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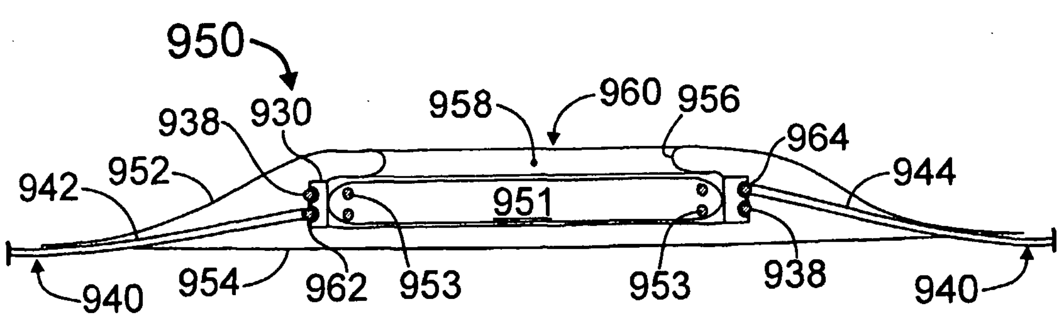
(54) **Title:** MOUNTING TRANSPONDERS AND ANTENNAS IN PNEUMATIC TIRES



(57) **Abstract:** Method and apparatus for mounting a transponder module (400, 702, 951, 1000, 1020, 1751, 1752, 1852, 1852', 1951, 1951a) and a separate antenna (1520, 1520', 1520'', 1620, 1720, 1820, 1920) to an inner surface (1504, 1504', 1504'', 1704, 1804) of a pneumatic tire (312, 650, 1204, 1350, 1350', 1550, 1550', 1550''), and for coupling the transponder module to the antenna by means of coupling coils which are included with the transponder module (450, 760, 953, 1004, 1024) and the antenna (750, 750', 866, 938, 968, 1538, 1538', 1538'', 1638, 1638', 1738, 1738', 1838, 1838', 1938). The transponder module mounting methods generally allow it to be inserted, removed, or accessed for maintenance at any time during the tire's life cycle, and allow sensing access to the tire's inner atmosphere.

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MOUNTING TRANSPONDERS AND ANTENNAS IN PNEUMATIC TIRES

Description of **WO0136221**

MOUNTING TRANSPONDERS AND ANTENNAS IN PNEUMATIC TIRES
CROSS-REFERENCE TO RELATED APPLICATIONS
This application is a continuation-in-part of commonly-owned, copending US Provisional Patent Application No. 60/095,176, filed 8/3/98 by Brown and Pollack. This application is related tocommonly-owned, copending PCT Patent Application No.

PCT/US99/17403 entitled MOUNTING TRANSPONDERS IN PNEUMATIC TIRES filed July 29,1999 andcommonly-owned, copending PCT Patent Application No.

PCT/US99/17250 entitled ANTENNAS FOR TRANSPONDERS IN PNEUMATIC TIRES filed July 29,1999, both to a common assignee.

TECHNICAL FIELD OF THE INVENTION
The invention relates to the mounting of electronic devices such as transponders and antennas in pneumatic tires, and to the coupling of transponders to antennas in pneumatic tires.

BACKGROUND OF THE INVENTION
THE ASSIGNEE'S ONGOING DEVELOPMENT EFFORTS
For a century, the Goodyear Tire & Rubber Company of Akron Ohio, assignee of the present invention, has been the uncontested industry leader in tire product technology.

For example, as early as 1892, a puncture-resistant tire was patented. In 1934, a year recognized as the beginning of the run-flat era, Goodyear introduced the Lifeguard(tm) safety tube, a fabric tube within the tire, used commercially by auto makers and on trucks.

In 1993, Goodyear's Eagle GS-C EMT (Extended Mobility Tire) won the Discover Award for Automotive Technological Innovation. In 1996, the Goodyear Eagle F1 run-flat tire was chosen as standard equipment on the 1997 Chevrolet C-5 Corvette.

Other examples of the strides Goodyear has taken in the advancement of tire and related technologies includes, but is not limited to, the following patented inventions:
Commonly-owned U. S. Patent No. 3, 665, 387 (Enabnit; 1972), entitled
SIGNALLING SYSTEM FOR LOW TIRE CONDITION ON A VEHICLE, incorporated in its entirety by reference herein, discloses a low tire pressure warning system adaptable for any number of wheels of a vehicle and providing dashboard indications of system operation and low pressure conditions while the vehicle is in motion.

Commonly-owned U. S. Patent No. 3. 831. 161 (Enabnit; 1974), entitled FAIL-SAFE MONITORING APPARATUS, incorporated in its entirety by reference herein, discloses monitoring vehicle tire pressure wherein the operator is warned of an abnormal or unsafe condition of one or more of the tires.

Commonly-owned U. S. Patent No. 3, 872. 424 (Enabnit; 1975), entitled
APPARATUS AND METHOD FOR TRANSMITTING AUXILIARY SIGNALS ON
EXISTING VEHICLE WIRING, incorporated in its entirety by reference herein, discloses communicating with low tire pressure monitoring circuits using power pulses carried on existing vehicle wiring (e. g., the turn signal circuits).

Commonly-owned U. S. Patent No.4 052. 696 (Enabnit; 1977), entitled TIRE
CONDITION MONITOR, incorporated in its entirety by reference herein, discloses a tire condition sensing circuit that includes a ferrite element that changes from a ferromagnetic to a non-ferromagnetic state in response to a temperature increase above the material Curie point.

Commonly-owned U. S. Patent No. 4,099. 157 (Enabnit; 1978), entitled SINGLE

WIRE POWER/SIGNAL SYSTEM FOR VEHICLE AUXILIARY DEVICES, incorporated in its entirety by reference herein, discloses providing both power to and receiving detection signals froma remotely located condition monitoring device using a single wire with ground return through the vehicle frame.

Commonly-owned U. S. Patent No. 4.108. 701 (Stanley; 1978), entitled METHOD FOR MAKING HOSE INCORPORATING AN EMBEDDED STATIC GROUND CONDUCTOR, and related U. S. Patent No. 4, 168, 198 (Stanley; 1979), entitled APPARATUS FOR MAKING HOSE INCORPORATING AN EMBEDDED STATIC GROUND CONDUCTOR, both incorporated in their entirety by reference herein.

Commonly-owned U. S. Patent No.4. 911, 217 (Dunn, et. al.; 1990), entitled INTEGRATED CIRCUIT TRANSPONDER IN A PNEUMATIC TIRE FOR TIRE IDENTIFICATION, incorporated in its entirety by reference herein, discloses an RF transponder in a pneumatic tire. Figure la of this patent illustrates a prior-art identification system ("reader") that can be used to interrogate and power the transponder within the tire.

The identification system includes a portable hand-held module having within it an exciter and associated circuitry for indicating to a user the numerical identification of the tire/transponder in response to an interrogation signal.

Commonly-owned U. S. Patent No. 5. 181. 975 (Pollack, et. al.; 1993), entitled INTEGRATED CIRCUIT TRANSPONDER WITH COIL ANTENNA IN A PNEUMATIC TIRE FOR USE IN TIRE IDENTIFICATION, incorporated in its entirety by reference herein, discloses a pneumatic tire having an integrated circuit(IC) transponder and pressure transducer. As described in this patent, in a tire that has already been manufactured, the transponder may be attached to an inner surface of the tire by means of a tire patch or other similar material or device.

Commonly-owned U. S. Patent No.5. 218, 861 (Brown, et al.; 1993), entitled PNEUMATIC TIRE HAVING AN INTEGRATED CIRCUIT TRANSPONDER AND PRESSURE TRANSDUCER, incorporated in its entirety by reference herein, discloses a pneumatic tire having an integrated circuit(IC) transponder and pressure transducer mounted within the pneumatic tire. Upon interrogation (polling) by an external RF signal provided by a"reader", the transponder transmits tire identification and tire pressure data in digitally-coded form. The transponder is"passive"in that it is notself-powered, but rather obtains its operating power from the externally-provided RF signal.

The commonly-owned U. S. Patents referenced immediately hereinabove are indicative of the long-standing, far-reaching and ongoing efforts being made by the Goodyear Tire & Rubber Company in advancing tire product technology.

TIRE TRANSPONDER SYSTEMS. GENERALLY

As used herein, a"transponder"is an electronic apparatus (device) capable of monitoring a condition such as air pressure within a pneumatic tire, and then transmitting that information to an external device. The external device can be either an RF (radio frequency) reader/interrogator or, simply an RF receiver. A simple receiver can be used when the transponder is"active", and has its own power source. A reader/interrogator would be used when the transponder is"passive"and is powered by an RF signal from the reader/interrogator. In either case, in conjunction with the external device, the transponder forms a component of an overall tire-conditionmonitoring/warning system. In order to send or receive RF signals, a transponder must have an antenna. This antenna may either be incorporated into the transponder module itself, or it may be external to the transponder module and electrically connected or coupled to it in a suitable manner.

U. S. Patent No. 5,500, 065, incorporated in its entirety by reference herein, and discussed in greater detail hereinbelow illustrates (at Figure 2 thereof) an exemplary prior art transponder within a tire, and illustrates (at Figure 5 thereof) an exemplary prior art interrogator which can be used to communicate with and retrieve digitally coded information from the transponder. This patent discloses various methods, described in greater detail hereinbelow, for mounting, including embedding during manufacturing the tire, the transponder (monitoring device) within the tire.

Commonly-owned U. S. Patent No. 4, 911. 217, incorporated in its entirety by reference herein, illustrates (at Figure la thereof) another exemplary prior art interrogating tire identification system (10) in combination with a passive integrated circuit transponder (24) in a tire (22).

Safe, efficient and economical operation of a motor vehicle depends, to a significant degree, on maintaining the correct air pressure in all (each) of the tires of the motor vehicle.

Failure to correct quickly forfaulty/abnormal (typically low) air pressure may result in excessive tire wear, blow-outs, poor gasoline mileage and steering difficulties.

The need to monitor tire pressure when the tire is in use is highlighted in the context of"run-flat" (driven deflated) tires, tires which are capable of being used in a completely deflated condition. Such run-flat tires, as disclosed for example in commonly-owned U. S.

Patent No. 5. 368. 082, incorporated in its entirety by reference herein, may incorporate reinforced sidewalls and mechanisms for securing the tire bead to the rim to enable a driver to maintain control over the vehicle after a catastrophic pressure loss, and are evolving to the point where it is becoming less and less noticeable to the driver that the tire has become deflated. The broad purpose behind using run-flat tires is to enable a driver of a vehicle to continue driving on a deflated pneumatic tire for a limited distance (e. g., 50 miles, or 80 kilometers) prior to getting the tire repaired, rather than stopping on the side of the road to repair the deflated tire. Hence, it is generally desirable to provide a low-pressure warning system within the vehicle to alert (e. g., via a light on the dashboard, or a buzzer) the driver to the loss of air in a pneumatic tire. Such warning systems are known, and do not form part of the present invention, per se.

Numerous tire-pressure warning systems are known in the art. Representative examples of such may be found in the patent references described hereinbelow. The present invention is not limited to a particular type of transponder.

Although the use of pressure transducers in pneumatic tires (in association with electronic circuitry for transmitting pressure data, such as transponder) is generally well known, these pressure-data systems for tires have been plagued by difficulties inherent in the tire environment. Such difficulties include effectively and reliably coupling RF signals into and out of the tire, the rugged use the tire and electronic components are subjected to, as well as the possibility of deleterious effects on the tire from incorporation of the pressure transducer and electronics in a tire/wheel system.

Tires for motor vehicles are either tubeless, or require an inner tube to maintain pressure in the tire. In either case, the tire is typically mounted on a wheel(rim). The use of an inner tube is typical of truck tires, in contrast to tubeless tires which are typically found on cars, pickup trucks, sports/utility vehicles, minivans and the like. The present invention is primarily directed to mounting a transponder within a tubeless tire.

For tubeless tires, various transponder mounting locations are known, and include (i) mounted to an inner surface of the tire, (ii) mounted to the wheel, and (iii) mounted to a valve stem. The present invention is primarily directed to mounting a transponder to an inner surface of the tire.

U. S. Patent No. 3. 787, 806 (Church, 1974), incorporated in its entirety by reference herein, discloses a tire pressure warning apparatus for operation in a pneumatic tire in combination with an inner tube. As described in this patent, means are provided to protect the individual components while permitting the necessary flexibility to conform to the shape and motion of the inner surface of the tire. The tire pressure warning apparatus (10) is vulcanized, or otherwise adhered (hermetically sealed) to an external (Figures 1-3) or internal (Figures 4-6) surface of an inner tube (18). More particularly, the tire pressure warning apparatus (10) comprises a pressure sensor (12), a transmitter (14) and a power supply such as a battery (16). The transmitter (14) is housed in an inflexible enclosure (24) such as a hard plastic box or the like. The battery (16) is housed in a suitable inflexible enclosure (22) such as a hard plastic box or the like. Leads (32,34) connecting the sensor (12) to the battery enclosure (22) and leads (36,38) connecting the battery enclosure (22) with the transmitter (14) are formed using stranded wire, and are coiled to permit flexing of the apparatus (10) without incurring wire breakage. The apparatus (10) is encased in any suitable elastic material (40) such as natural rubber or the like, to permit a flexibility comparable to that of the inner tube (18). In the embodiment (Figures 4-6) wherein the apparatus (10) is mounted to the inside of the inner tube(18A), the elastic material (40A) is seen to have areas of reduced thickness between the sensor (12A), battery (16A) and transmitter (14A) to readily permit flexing of the warning apparatus(10A). A key feature of the apparatus (10) of this patent is that the pressure sensor (12), transmitter (14) and power supply (16) are separate units connected to one another by flexible leads (32,34,36, 38) and surrounded by a flexible material (40) to generate a single composite unit and to permit flexing of each of

the separate units relative to one another, the flexible material being adhered to the inner tube and conforming in shape to the inner surface of the tire.

U. S. Patent No.5 285, 189 (Nowicki, et al. ; 1994), incorporated in its entirety by reference herein, discloses an abnormal tire condition warning system comprising a radio transmitting device (A) including a radio circuit (10), a tire condition sensor (20), a control circuit (11) and a battery power supply (12). The radio circuit (10), control circuit (11), sensor (20) and battery (12) are contained in a housing (16) typically of plastic or the like, including a base wall (18) which is configured for close reception against the wheel rim (22) in the tire wheel cavity. Typically, the housing (16) is attached by means of a band (24) and adjustable tightening means (26).

U. S. Patent No.4. 067, 235 (Markland, et al.; 1978), incorporated in its entirety by reference herein, discloses a tire pressure monitoring (measuring) system, and illustrates various embodiments of mounting a remote tire pressure sensor in or on a tire. As shown in
Figure 3, the remote tire pressure sensor (21) may be encapsulated by a suitable elastomeric compound and bonded to the wall of the tire (22). As shown in Figure 9, the tire pressure sensor(21') may be formed in the shape of a sphere and introduced inside of the tire as a free-rolling element. As shown in Figure 8, the tire pressure sensor (21") may be miniaturized and embedded within the casing of the tire (22) during manufacture. As shown in Figure 7, the tire pressure sensor(21'") may be incorporated into a repair plug inserted into the sidewall of the tire (22). Another feature illustrated (see Figures 3,7,8,9) in this patent is a receiving antenna 38 and a re-transmitting antenna 26, both of which are discussed in greater detail hereinbelow.

U. S. Patent No.4. 334. 215 (Frazier, et al.; 1982), incorporated in its entirety by reference herein, discloses monitoring heat and pressure within a pneumatic tire using a transmitter and other circuit elements mounted to a circuit board which is secured to the inside of the tire by an overlaying elastic adhesive material.

U. S. Patent No. 5. 500, 065 (Koch, et al.; 1996), hereinafter referred to as the"'065
Patent", incorporated in its entirety by reference herein, discloses a method for embedding a monitoring device ("tag") within a tire during manufacture. The device can be used for monitoring, storing and telemetering information such as temperature, pressure, tire mileage and/or other operating conditions of a pneumatic tire, along with tire identification information. The monitoring device (10) is comprised of a microchip (20), an antenna (30), an amplifier (42), a battery (44), a pressure sensor (46), and optional temperature and mileage/distance sensors, populating a circuit board (48). The monitoring device may optionally (but desirably) be contained (encased) in a rigid or semi-rigid encasement to enhance rigidity and inhibit straining of the device. The reinforcing encasement or encapsulation is a solid material, i. e., non-foam compounds, which are compatible with the tire rubber, such as various urethanes, epoxies, unsaturated polyesterstyrene resins, and hard rubber compositions. Figure1 of the'065 Patent illustrates a method of securing such a monitoring device (10 or 10') to an inner wall of a pneumatic tire(5) at two preferred locations: (i) in the vicinity of the tire bead below the end of the body plyturn-up where the sidewall bending stiffness is greatest and where the rolling tire stresses are at a minimum; and (ii) on the inside of the tire at the center of the tread crown where stresses from mounting and dismounting are at a minimum. The specific attachment or adhering means can be through the use of a chemical cure adhesive including a room temperature amine curable adhesive or a heat-activatable cure adhesive. Figures 7,8,9 and 10 of the'065
Patent illustrate additional methods of mounting a monitoring device within a tire. An encased monitoring device, or monitoring device assembly (17), can be adhered with a flexible cover (80) while resting on the inner surface of the tire (Figure 7), or while resting in a pocket formed in the inner surface of the tire (Figure 8). Suitable housing materials which function to hold the monitoring device to the tire include generally flexible and resilient rubbers such as natural rubber or rubbers made from conjugated dienes having from 4 to 10 carbon atoms such as synthetic polyisoprene, polybutadiene, styrene-butadiene rubber, and the like, flexible polyurethanes, flexible epoxides, and the like. The cover (80) is secured to an interior wall (7) of the tire. The cover (80) has an adhering surface which secures the monitoring device assembly to a surface of the tire, preferably within the pressurizable tire cavity. As shown in Figure 7 of the'065 Patent, the cover (80) may surround the monitoring device assembly (17), and is secured to the interior portion of the tire about the perimeter of the monitoring device assembly. As shown in Figure 8 of the '065 Patent, the monitoring device assembly (17) may be located within a tire pocket or recess (75) which can be made by inserting a rectangular billet of appropriate dimensions onto the uncured tire innerliner at the location of the desired recess (75). During tire manufacturing, the curing pressure of the mold will press the billet into the tire inner liner and cure in the recess pocket (75). The cover (80) is then

attached about the perimeter of the monitoring device assembly to the tire inner liner. The cover (80) may be co-cured with the green tire-or may be attached to the tire after curing by use of various types of adhesives, including ambient temperature amine curable adhesives, heat-curable adhesives, and chemical-curable adhesives such as variousself-vulcanizing cements, various chemical vulcanizing fluids, and the like. The flexible cover (80) can be attached to the tire with the monitoring device already in place or, alternatively, the monitoring device, whether or not encapsulated, can be inserted through a slot (84) in a flexible cover (80) which is already attached to the tire. Figures 11 and 12 of the'065 Patent illustrate another method of mounting a monitoring device within a tire. The monitoring device is contained within a housing pocket (90) which has a slot for mounting the assembly within the pocket and through which the antenna (30) of the monitoring device can project after assembly. A band (98) is included for securing and biasing the antenna (30) to a raised portion (102) of the pocket. Figures 13 and 14 of the'065 Patent illustrate a method of embedding the device within a tire, and includes placing the device between a tie-gum ply (199) and inner liner ply (200) of an uncured tire, at a location in the vicinity of the tire crown (202) or at a location near the tire bead (210), respectively. After curing, the device is permanently contained in the tire structure. Figure 15 of the'065 Patent illustrates another method of embedding the monitoring device assembly within a tire. The monitoring device assembly (17) is sandwiched between the uncured tire inner liner ply (200) and an inner liner patch (222).

After curing, the monitoring device assembly (17) is permanently embedded between the patch (222) and the ply (200).

U. S. Patent No.5, 731. 754 (Lee, Jr., et al.; 1998), incorporated in its entirety by reference herein, discloses a transponder and sensor apparatus (10) for sensing and transmitting vehicle tire parameter data. The apparatus (10) includes a substrate (12) which is preferably flexible. The substrate (12), various sensors, and a transponder (18) mounted on or adjacent to the substrate (12) are disposed in a housing (7) formed of an encapsulating medium. Preferably, the encapsulating medium (7) is formed of cured rubber for compatibility with a vehicle tire, and may be formed to any desired shape. As shown in Figure 7, the apparatus (10) may be integrally mounted within the tire (60) during the manufacture of the tire (60), and a suitable mounting position is in the upper portionof the side wall (66) adjacent to the bead (64), as this location exhibits the least amount of flexure during use of the tire (60). As shown in Figure 8, the apparatus (10) may be mounted on the inner liner of the tire (60) adjacent to the bead (64). In this case, the elastomeric patch or membrane (59) is mounted over the apparatus (10) and sealingly joined to the inner liner to fixedly mount the apparatus (10) in registry with the tire. Referring to Figure 2, another feature illustrated in this patent is an antenna (36).

An electronics package (module) including an RF transponder component of a tirecondition monitoring system may be mounted to an inner surface of a pneumatic tire, either after the tire is manufactured or during its manufacture. This electronics package will hereinafter generally be referred to as a"transponder module", or more simply as a "transponder".

One challenge associated with mounting the transponder (module), is ensuring that the pressure sensor component of the transponder is in fluid communication with the cavity of the tire so that air pressure within the tire can be detected/measured. The aforementioned '065 Patent (U. S. Patent No.5. 500, 065 proposes various solutions to this problem. Figure 6 of the aforementioned'065 patent illustrates, for example, providing an opening or aperture (18) in the encasement or encapsulating material (16) to allow an air path to the pressure sensor (46) so that it can measure the internal air pressure. Figures 7 and 8 of the aforementioned'065 patent illustrate, for example, providing a slit (84) in the cover (80) to allow for detection of air pressure. Figures 13 and 14 of the aforementioned'065 patent illustrate, for example, providing a small removable dowel (206) which will press through the inner liner ply portion (200) of the tire during curing to form a hole or aperture for air passage to the pressure sensor in the monitor assembly (transponder) (17). Figure 15 of the aforementioned'065 patent illustrates, for example, inserting a dowel (220) through the inner liner patch (222) and then into the transponder (17). The dowel must be removed after building the tire to allow fluid communication through the hole or aperture to the underlying pressure sensor. This represents an additional step which, if overlooked, can render the transponder inoperative for its intended purpose. Commonly-owned PCT Patent
Application No. PCT/US97/22570 discloses using a wicking means associated with the pressure sensor to provide a path for pressure equilibrium between the pressure sensor and the inflation chamber. Figure 6 of the aforementioned U. S. Patent No. 5,731, 754 discloses a transponder covering which is a thin elastomeric or rubber membrane (59) which transfers pressure from the interior of the tire to the pressure sensor (50) by means of a pressure transfer medium (57) which is disposed in the cavity between the membrane and sensor.

Typically, in the mounting techniques of the prior art, the transponder is not readily accessible for replacement or maintenance.

Another challenge when mounting a transponder or a housing (cover) for the transponder (see, e. g., Figure 10 and the cover 80 of the aforementioned U. S. Patent No.

5, 500.065) during building the tire, is inherent in putting any"foreign object"on the tire building drum during lay-up of the green tire. Such a"lump"on an otherwise substantially cylindrical build drum can interfere with (adversely affect) the spacing and/or alignment of cords (wire filaments) laid across (typically in the axial direction) the build drum. These cords are typically on the order of approximately 0.15-0.30 mm in diameter, spaced uniformly, circumferentially about the build drum
Another challenge when mounting a transponder in a tire during building the tire is inherent in the high levels of heat generally applied during this process. Many electronic components found in the typical transponder are sensitive to such levels of heat, and may be damaged in the process. Alternately, custom-designed and therefore more expensive electronics may need to be selected for use in transponders intended for this kind of use.

ANTENNA DESIGN AND LOCATION CONSIDERATIONS
An antenna is evidently an important feature of an RF transponder, and specific mention of this feature has been made hereinabove. Generally speaking, there are two main configurations and locations for the antenna of a tire transponder: (i) a"coil"antenna, typically located with the transponder in a package; and (ii) a"loop"antenna extending from the transponder about the circumference of the tire.

In addition to these two main configurations and locations, U. S. Patent No.

4, 857. 893 (Carroll; 1989), incorporated in its entirety by reference herein, discloses a configuration wherein all electrical circuits of a transponder device, as well as an antenna (receiving/transmitting coil), may be realized on a single monolithic semiconductor chip.

Figures 3,7,8 and 9 of the aforementioned U. S. Patent No.4. 067. 235 illustrate various configurations and locations of antennas for transponders. As illustrated in Figure 1, the remote tire pressure sensor (transponder, 21) includes two antennas: (i) a secondary receiving antenna (38); and (ii) a secondary re-transmitting antenna (26). As mentioned above, Figure 3 illustrates a remote tire pressure sensor (21) encapsulated by a suitable elastomeric compound and bonded to the inner wall of the tire (22). The entire electronic circuit is placed on a semiconductor body or wafer and is surrounded by the secondary receiving antenna (38). Directly below the wafer is the secondary re-transmitting antenna (26). Both antennas (38 and 26) are located within the elastomeric compound encapsulating the remote tire pressure sensor (21). Figure 8 illustrates an arrangement wherein the secondary receiving antenna (38) is wound around the circumference of the sensor (21"), and the secondary re-transmitting antenna (26) is disposed closely adjacent the semiconductor body (128). Figure 7 illustrates the secondary receiving antenna (38) extending around and within the periphery of the sensor(21'"), and the secondary retransmitting antenna (26) disposed closely adjacent the semiconductor body (128). Figure 9 illustrates a remote tire pressure sensor(21') in the shape of a sphere which can be introduced inside the tire (22) as a free-rolling element. The sensor(21') includes a secondary receiving antenna (38) that is circumferentially wound around the surface of the sphere. The secondary re-transmitting antenna (26) is located near the center of the sphere.

Figure 2 of the aforementioned U. S. Patent No 5, 731, 754 illustrates locating the antenna (36) as being a patch antenna mounted on a substrate (12) upon which are also mounted other components of the transponder, such as a battery (14), pressure sensing means (50) and other electronic components (e. g., temperature sensor (110), means (120) for detecting tire revolution, and a timer (134)).

Figure 11 of the aforementioned U. S. Patent No.5. 500, 065 illustrates an antenna extending from a housing pocket (90) which has a cavity (94) for holding the monitoring device assembly. The pocket (90) also includes a band (98) for securing and biasing an antenna (30) of the monitoring device assembly to a raised portion (102) of the pocket.

The above-described antenna configurations and locations are all examples of small, typically coil antennas which are located with the transponder module itself. There follows a description of a loop-type antenna which extends around the circumference of the tire.

PCT Patent Application No. PCT/US90/01754 (published 18 October 1990 asW090/12474), incorporated in its entirety by reference herein, discloses a vehicle tire identification system wherein electronic transponders (20) are embedded within vehicle tires (40). The transponder includes a receiver/transmitter coil (26) of one or more loops of wire (54) strategically placed along the sidewall or in proximity to the tread face of the tire. The coil (26) functions as an antenna for the transponder (20) and is coupled to a coil (14) functioning as the antenna of an interrogator (reader/exciter) unit. A typical vehicle tire (40) is shown in Figure 2. Its inner circumference is reinforced by a bead (41) which is a closed loop of wire. The sensitivity of the transponder antenna/coil (44) is adversely affected if it is too close to the bead (41). Conversely, the tread face (42) of the tire is subject to wear and therefore it is important to locate the coil (44) away from the wear hazard of the tread (42). Figure 3 illustrates various possible locations for the antenna/coil (44A, 44B, 44C) which is embedded within the carcass of the tire. Figure 4 illustrates alternative locations for the transponder wires (antenna/coil). For example, at a location (50) which is inside the steel belts but near the inner surface of the tire (45), or at a location(51) which is between layers of steel belts, or at a location (52) which is just outside of the belts and within the tread of the tire. A typical tire transponder is shown in Figure 5, wherein it can be seen that the transponder antenna/coil (54) is formed of one or more turns of insulated wire or bare wire separated by insulating rubber in the manufacturing process.

Acceptable materials for the wire include steel, aluminum, copper or other electrically conducting wire. As disclosed in this patent document, the wire diameter is not generally considered critical for operation as an antenna for a transponder. For durability, stranded steel wire consisting of multiple strands of fine wire is preferred. Other wire options available include ribbon cable, flexible circuits, conductive film, conductive rubber, etc.

The type of wire and number of loops in the antenna/coil is a function of the anticipated environment of the tire use and the preferred distance of interrogator communication. It is proposed in this patent document that the greater the number of loops of the transponder coil, the greater the distance of successful interrogation of a given tire transponder.

The aforementioned, commonly-owned U. S. Patent No.5, 181, 975 discloses a pneumatic tire having an integrated circuit transponder which, upon interrogation by an external RF signal, transmits tire identification and/or other data in digitally-coded form.

The transponder has a coil antenna of small enclosed area as compared to the area enclosed by an annular tensile member comprising a bead of the tire. The annular tensile member, during transponder interrogation, acts as the primary winding of a transformer. The coil antenna is loosely coupled to the primary winding and is the secondary winding of the transformer. The coil antenna is substantially planar in shape and, when positioned between the inner liner of the tire and its carcass ply, the transponder may include a pressure sensor responsive to tire inflation pressure. See also the aforementioned, commonly-owned U. S.

Patent No. 5, 218, 861.

U. S. Patent No. 4, 319, 220 (Pappas, et al.; 1982), incorporated in its entirety by reference herein, discloses a system for monitoring tire pressure comprising wheel units in the tires and a common receiver. Each wheel unit has an antenna comprising a continuous wire loop embedded in an open annulus which is disposed against the inner periphery of the tire for transmitting signals and for receiving power. The antenna (152) is held against the inner periphery of the tire by its resilience and by centrifugal force. Further, to prevent side-to-side shifting when the vehicle stands still, two or three preferably molded side guides(153) are disposed into the tire. As illustrated in Figures 9,10 and 11, the antenna (152) annulus is formed as an almost complete circle having a gap between its two ends. Wires (155) within the antenna (152) emerge as a pair of output wires (159a, 159b) at a single location from the open annulus. At symmetrical locations about the inside of the antenna, an electro-magnetic power generator module, a gas-mass monitoring sensor module, and a signal transmitter are mounted, electrically interconnected, and suitably connected to the antenna wires159a/159b. The interconnection wires(119a, 119b, 119c, 139a, 139b) are disposed on or in the inner surface of the antenna assembly.

U. S. Patent No.5, 479, 171 (Schuermann; 1995), incorporated in its entirety by reference herein, discloses a long, narrow antenna (14), as illustrated in Figures 3,4a and 4b, mounted to or within the sidewall (30) of a tire. This antenna acts to extend the reading range for the interrogator to be a long range which is generally radially symmetrical about the tire. The antenna (14) comprises a wire which is folded

back upon itself and has a coupling coil (16) formed at an end thereof. A transponder (12) has a coil (132) which may be formed as an annulus surrounding other components of the transponder (see Fig. 6) or which may be wound on a small ferrite core (220) (see Fig. 7). The attachment methods described are to affix the antenna (14) and the transponder (12) using an adhesive patch (32), or to use an integrated manufacturing process in which the antenna and transponder might be formed directly within the structure of the sidewall (30) of the tire (20).

It is thus evident that the selection of antenna type and location are non-trivial issues warranting careful design consideration, including issues of how best to connect a given antenna type to a given transponder.

TRANSPONDER-MOUNTING LOCATIONS
Other issues relevant to mounting a transponder module in a tire include replacing the entire transponder module if it requires replacement and, in the case of battery-powered ("active") transponders, replacing the battery if required. Preferably, the transponder, whether"active"or"passive"should represent only a fractional cost of the overall tire.

Hence, replacing an entire tire because of an inoperative transponder would be highly undesirable.

In the case, for example, of a transponder unit mounted to the rim, rather than to the tire, such as is shown in the aforementioned U. S. Patent No.5, 285, 189, replacement of the transponder unit would be a relatively straightforward matter of removing the tire from the rim, replacing the transponder unit, and re-installing the tire on the rim.

In contrast thereto, consider the case, for example, of the aforementioned U. S.

Patent No. 4. 067, 235 wherein (see, e. g., Figure 3 thereof) the remote tire pressure sensor (21) is encapsulated by a suitable elastomeric compound and is bonded to the wall of the tire (22), replacing the transponder would require de-bonding the elastomeric compound encasing the tire pressure sensor and re-bonding another unit to the wall of the tire. Such procedures require special care and consideration and may, in certain instances, not be feasible without causing damage (however slight) to the tire.

If, as in the aforementioned PCT Patent Application No. PCT/US90/01754 the antenna is an integral element of the tire, embedded in the carcass of the tire, problems would evidently accrue to detaching the transponder from the antenna, and re-connecting a replacement transponder to the embedded antenna-assuming, arguendo, that the transponder itself is not embedded in the carcass of the tire. The patent document describes, for example, how an integrated circuit of an electronic module (55) of a transponder may be mounted on a circuit board or substrate providing for attachment of the transponder antenna/coil wires (54) by any suitable means including welding, soldering, bonding or suitable cement.

In the case of permanently embedding the transponder within the tire, such as is shown at Figure 13 of the aforementioned U. S. Patent No. 5.500. 065, replacing the transponder unit or any component thereof is a virtual impossibility.

The aforementioned, commonly-owned U. S. Patent No.5, 181. 975 discloses a number of locations and techniques for mounting a transponder (24) within a tire. In a tire that has already been manufactured, the transponder (24) may be attached to the axially inner side of the inner liner (30) or to the axially outer side of the tire sidewall (44) by means of a tire patch or similar material or device. (see, e. g., column 11, lines 61-65).

Commonly-owned U. S. Patent No.5 218, 861 also discloses locations and techniques for mounting an integrated circuit transponder and pressure transducer within a pneumatic tire.

A final design challenge, whether or not recognized as such by the prior art, is to provide a single, or readily modified method and apparatus for mounting a variety of transponders within a variety of pneumatic tires, with as much commonality between the variations as is possible.

ASPECTS AND SUMMARY OF THE INVENTION
It is an aspect of the present invention to provide method and apparatus for mounting an electronic device such as a transponder module and an antenna in a pneumatic tire, asdefined in one or more of the appended claims and, as such, having the capability of being implemented in a manner to accomplish one

or more of the subsidiary aspects.

It is another aspect to provide method and apparatus for mounting a transponder module in a pneumatic tire in a manner such that the transponder may conveniently be inserted, removed, replaced and/or maintained, either during tire manufacture or after, and such that a sensor associated with the transponder is exposed to conditions within the tire.

It is another aspect of the present invention to provide method and apparatus for mounting a transponder and an antenna for the transponder within a pneumatic tire, and to provide for removable connections between the transponder and the antenna.

It is another aspect of the present invention to mount the transponder and a separate antenna within a pneumatic tire in a way which provides effective transformer-type coupling between a transponder coupling coil and an antenna coupling coil.

It is another aspect of the invention to provide a method for mounting a transponder module in a pneumatic tire at any point in the tire manufacturing process, with minimal impact on tire performance.

According to the invention, a patch for mounting a transponder module to an inner surface of a pneumatic tire has a body formed of a resilient material. An opening extends from an external surface of the patch to a cavity. The cavity is sized and shaped to be approximately the same size and shape as the transponder module. The patch is preferably formed of a resilient material, such as halobutyl rubber. The opening preferably has a smaller dimension than the cavity, thereby forming a resilient lip about the opening, the lip being sized somewhat smaller in a corresponding dimension than the transponder module so that the transponder module may be inserted through the opening into the cavity by deflecting the lip and thereafter retained within the cavity by the annular lip. In an embodiment of the invention, the opening is circular and the lip is annular. At least one slot may be provided on the lip to facilitate deflecting the lip for inserting the transponder module past the lip into the cavity.

In an alternate embodiment of the invention, a transponder holder with a plastic housing having a similar cavity and a deflectable retaining lip or a screw-on retaining cap can be used to hold a transponder module.

According to a feature of the invention, a coupling coil comprising at least a few turns of wire is disposed within the body of the patch or housing closely adjacent the cavity.

The coupling coil is preferably concentric with the circumference of the cavity, and may either surround that circumference or be positioned close below it (on the side of the cavity opposite its opening). The coupling coil may be formed integrally with the patch, during a molding process, or may be disposed around or within a bobbin which is molded into the body of the patch/housing.

According to a feature of the invention, an antenna is provided, having two end portions, each of which are electrically connected to a respective end of the coupling coil.

The antenna extends circumferentially about an inner surface of the tire.

In an alternate embodiment of the invention, contact pads or plugs are provided in the patch, and the antenna is electrically connected to these pads/plugs. In this manner, a transponder module having contact pads on an external surface thereof may be electrically connected to the antenna when the transponder module is disposed within the cavity.

According to an aspect of the invention, the antenna may be a wire which is embedded in one or more elongate rubber strips which are disposed circumferentially about an inner surface of the tire. The wire may be an elongate helix, or a single elongate strand of wire, or multiple strands of wire, or braided wire. Alternatively, the wire may, in essence, be a conductive pathway formed of a material selected from the group consisting of carbon containing material, carbon fiber, carbon black and particulate graphite. These rubber antenna strips may be integrally molded with the patch or housing.

According to a feature of the invention, end portions of the strips of rubber within which the antenna wires are embedded are of a conductive rubber composition. In this manner, when these end portions are overlapped, a complete 360 degree loop antenna may be formed on an inside circumferential surface of

the tire.

According to alternate embodiments, antenna wires emanating from the patch as described hereinabove may be disposed circumferentially about the inner surface of the tire without electrically connecting the outer ends, thus forming a dipole antenna, instead of a loop antenna.

In an alternate embodiment of the invention, a coupling coil for an external antenna is disposed in a patch which does not have a cavity for the mating transponder module, and the transponder module is attached to the antenna coupling coil in a way which positions the transponder coupling coil in close proximity and concentric to the antenna coupling coil, thereby providing effective transformer-type coupling between the transponder and the antenna. Mounting to the inner surface can be accomplished by embedding under the surface during tire manufacture, or by attaching on to the surface during or after tire manufacture. The antenna coupling coil may be pre-formed, or coiled around or within a bobbin.

In alternate embodiments of the invention, the antenna coupling coil and the transponder module are provided with corresponding mating features which facilitate their attachment one to the other with effective transformer-type coupling. The mating features also generally allow the transponder module to be inserted, removed, or accessed for maintenance at any time during the tire's life cycle, and allow sensing access to the tire's inner atmosphere. The mating features are: a recess to a protrusion, a screw-shaped protrusion to a mating hole, resilient housing clip fingers to a retaining edge on the transponder module, and a housing with a screw cap to an appropriately-shaped transponder module. The mating features can be provided: on the antenna coupling coil itself or on a bobbin containing it; on an elastomeric patch which removably holds the transponder module in a cavity; on a resilient housing which removably holds the transponder module in a cavity; or as features of the transponder module.

According to an aspect of the invention, any of the antennas described hereinabove (with or without integral coupling coils) may be attached to the inner surface of the tire, either during or after the tire-building process; or they may be embedded in the inner layer (s) of the tire during the tire-building process. Accordingly, any of the patch embodiments may likewise either be embedded under or attached on the inner surface.

Other aspects, features and advantages of the invention will become apparent from the description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference will be made in detail to preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings (Figures). The drawings are intended to be illustrative, notlimiting. Although the invention will be described in the context of these preferred embodiments, it should be understood that it is not intended to limit the spirit and scope of the invention to these particular embodiments.

Certain elements in selected ones of the drawings may be illustrated not-to-scale, for illustrative clarity.

Often, similar elements throughout the drawings may be referred to by similar referencenumerals. For example, the element 199 in a figure (or embodiment) may be similar in many respects to the element 299 in another figure (or embodiment). Such a relationship, if any, between similar elements in different figures or embodiments will become apparent throughout the specification, including, if applicable, in the claims and abstract.

In some cases, similar elements may be referred to with similar numbers in a single figure. For example, a plurality of elements 199 may be referred to as 199a,199b, 199c, etc.

The cross-sectional views, if any, presented herein may be in the form of"slices", or "near-sighted"cross-sectional views, omitting certain background lines which would otherwise be visible in a true cross-sectional view, for illustrative clarity.

The structure, operation, and advantages of the present preferred embodiment of the invention will become further apparent upon consideration of the following description taken in conjunction with the accompanying drawings, wherein:
Figure1A is a top plan view of a transponder module, according to a background for the invention;
Figure 1B is a side cross-sectional view of the transponder module of Figure1A, taken on a line1B-1B

through Figure 1A, according to a background for the invention;
Figure 2A is a top plan view of another transponder module 200, according to a background for the invention;
Figure 2B is a side cross-sectional view of the transponder module 200 of Figure 2A, taken on a line 2B-2B through Figure 2A, according to a background for the invention;
Figure 3A is a side cross-sectional view of a technique for preparing a transponder module for mounting to an inner surface of a pneumatic tire, according to a background for the invention;
Figure 3B is a schematic illustration of a transponder module mounted in the manner described in Figure 3A to an inner surface of a pneumatic tire, shown in cross-section, according to a background for the invention;
Figure 4A is a top plan view of an embodiment of a transponder module which is similar to the transponder module shown in Figure1A with an additional electronic component disposed in an outer chamber of the package, according to a background for the invention;
Figure 4B is a side cross-sectional view of the transponder module of Figure 4A, taken on a line4B-4B through Figure 4A, according to a background for the invention;
Figure 5A is a top plan view of an embodiment of a transponder module, similar to the embodiment shown in Figure 4A with an additional electronic component disposed outside of the module and connected to a circuit module which is within the module, according to a background for the invention;
Figure5B is a side cross-sectional view of the transponder module of Figure 5A, taken on a line5B-5B through Figure 5A, according to a background for the invention;
Figure 5C is a side view of the transponder module 500 of Figure 5A, taken on a line5C-5C, according to a background for the invention;
Figure 6A is a top plan view of a patch for retaining a transponder module for mounting to an inner surface of a pneumatic tire, according to the invention;
Figure 6B is a cross-sectional view of a transponder module disposed within the patch of Figure 6A for mounting to an inner surface of a pneumatic tire which is shown in conjunction with a build drum, according to the invention;
Figure 6C is a cross-sectional view of another embodiment of a transponder module disposed within the patch of Figure 6A for mounting to an inner surface of a pneumatic tire, according to the invention;
Figure 7A is a top plan view of another embodiment of a patch for retaining a transponder module for mounting to an inner surface of a pneumatic tire, and having a coupling coil incorporated therein, according to the invention;
Figure 7B is a side cross-sectional view (cross-hatching omitted, for illustrative clarity) of the patch of Figure 7A, taken on a line 7B-7B through the patch of Figure 7A, according to thel
Figure 7C is a side cross-sectional view (cross-hatching omitted, for illustrative clarity) of the patch of Figure 7B with a transponder module retained in a cavity in the patch, according to the invention;
Figure 7D is a side cross-sectional view (cross-hatching omitted, for illustrative clarity) of the patch of Figure 7B, with an alternate configuration for antenna wires emerging from the patch, according to the invention;
Figure 8 is a side cross-sectional view of a mold for molding a patch, according to the invention;
Figure 8A is a side cross-sectional view of an alternate embodiment of a mold half for molding a patch, according to the invention;
Figure 8B is a side cross-sectional view (cross-hatching omitted, for illustrative clarity) of a patch made by the technique described with respect to Figure 8A, according to the invention;
Figure 9A is a side cross-sectional view of an alternate embodiment of a mold for molding a patch, according to the invention;
Figure 9B is a side cross-sectional view (cross-hatching omitted, for illustrative clarity) of a patch made by the technique described with respect to Figure 9A, according to the invention;
Figure 9C is a side cross-sectional view (cross-hatching omitted, for illustrative clarity) of an alternate embodiment of a patch, according to the invention;
Figure10A is a side plan view, partially sectioned, of a transponder module suitable for being retained by one or more of the aforementioned patches, according to the invention;
Figure10B is a side cross-sectional view of an alternate embodiment of a transponder module suitable for being retained by one or more of the aforementioned patches, according to the invention;
Figure 11 is an exploded, side cross-sectional view (cross-hatching omitted, for illustrative clarity) of an alternate embodiment of a patch and an alternate embodiment of a corresponding transponder module, according to the invention;
Figure11A is an exploded, side cross-sectional view (cross-hatching omitted, for illustrative clarity) of an alternate embodiment of the patch and corresponding module illustrated in Figure 11, according to the invention;
Figure 12A is a side plan view, partially sectioned, of a tire with a patch and an antenna mounted therein,

according to the invention;
Figure 12B is a cross-sectional view of the tire of Figure 12A, taken on a line 12B12B through Figure 12A, according to the invention;
Figure 12C is a perspective view of an embodiment of an antenna for a transponder mounted within a tire, according to the invention;
Figure 13A is a perspective view of an alternate embodiment of an antenna for a transponder mounted within a tire, according to the invention;
Figure 13B is a cross-sectional view of an alternate embodiment of an antenna for a transponder mounted within a tire, according to the invention;
Figure 13C is a cross-sectional view of an antenna, such as the type shown in
Figure 13B, mounted with a transponder in a patch within a tire, according to the invention;
Figure 13D is a cross-sectional view of an alternate embodiment of an antenna, mounted with a transponder in a patch within a tire, according to the invention;
Figure 14A is an exploded, side cross-sectional view (cross-hatching omitted from certain elements, for illustrative clarity) of a technique for mounting a transponder module within a patch and making connections to an antenna such as the type shown in Figure 13B, according to the invention;
Figure 14B is a side cross-sectional view of an alternate embodiment of an antenna, suitable for use in the technique described with respect to Figure 14A, according to the invention;
Figure 14C is an exploded, side cross-sectional view of a technique for molding a patch with an integral antenna, and contact plugs for connecting to a transponder module disposed in a cavity of the patch, according to the invention;
Figure 15A is a top plan view of a patch with antenna strips containing a coupling coil and antenna for mounting to an inner surface of a pneumatic tire, according to the invention;
Figure 15B is a side cross-sectional view, taken on a line 15B-15B through the patch and antenna strips of Figure 15A, of a coupling coil/bobbin and antenna (helix shown in full view) disposed within the patch of Figure 15A for mounting to an inner surface (not shaded for clarity) of a pneumatic tire, according to the invention;
Figure 15C is a side cross-sectional view, showing a patch and antenna strips similar to those of Figure 15B embedded under the inner surface (not shaded for clarity) of a pneumatic tire, according to the invention;
Figure 15D is a side cross-sectional view of a coupling coil/bobbin and antenna embedded under the inner surface (not shaded for clarity) of a pneumatic tire, without a separate patch or strips, according to the invention;
Figure 16A is a cross-sectional view of an alternate embodiment of a coupling coil for mounting in various patches, housings, or directly in the tire wall, according to the invention;
Figure 16B is a cross-sectional view of an alternate embodiment of a coupling coil within an alternate embodiment of a bobbin for mounting in various patches, housings or directly in the tire wall, according to the invention;
Figure 17A is a cross-sectional view of a transponder (shown in full view) in a transponder-holding patch for mounting above an alternate embodiment of a coupling coil and antenna, according to the invention;
Figure 17B is a cross-sectional view of a transponder (shown in full view) in an alternate embodiment of a transponder-holding patch for mounting above an alternate embodiment of a coupling coil and antenna, according to the invention;
Figure 18A is a cross-sectional view of an alternate embodiment of a transponder (shown in full view) for mounting above an alternate embodiment of the coupling coil and antenna of Figure 17B, according to the invention;
Figure 18B is a cross-sectional view of an alternate embodiment of the transponder of Figure 18A for mounting above an alternate embodiment of the coupling coil and antenna of Figure 18A, according to the invention;
Figure19A is a top plan view of a housing having a central cavity surrounded by clip fingers for retaining a transponder in the cavity, according to the invention;
Figure19B is an exploded side cross-sectional view, taken on a line19B-19B through the housing of Figure19A, and showing a full side view of a transponder module suitable for insertion in the housing, according to the invention;
Figure19C is a side cross-sectional view of an alternate embodiment of the housing of Figure19B, according to the invention;
Figure19D is a side cross-sectional view of an alternate embodiment of the housing of Figure19B, according to the invention;
Figure19E is a side cross-sectional view of an alternate embodiment of the housing of Figure19D with a coupling coil disposed in the bottom portion, according to the invention; and
Figure19F is a side cross-sectional view of an alternate embodiment of the housing of Figure19B with the

chamber surrounded by a threaded cylindrical wall and having a mating screw cap to cover the chamber which is shown holding a transponder module (in full view) in the chamber, according to the invention.

DETAILED DESCRIPTION OF THE INVENTION
AN EXEMPLARY TRANSPONDER MODULE
Figures1A and 1B, comparable to Figures 9A and 9B of the commonly-owned, copending PCT Patent Application No. PCT/US98/07578, illustrate an exemplary transponder module 100 for monitoring tire pressure. The present invention is not limited to this particular exemplary transponder module.

In this exemplary transponder module 100, circuitry is encapsulated in an encapsulation package (housing) 104 that has two side-by-side chambers 112 and 114 which can be filled with potting compound. In this and subsequent examples of transponder modules (e. g., 200), the potting compound is omitted from the illustrations for illustrative clarity, it being understood that the present invention is suitable for retaining a variety of transponder modules, whether potted or not, on an inside surface of a tire, as described in greater detail hereinbelow.

The encapsulation package 104 has a generally planar base portion 106. The base portion 106 has an inner surface 106a and an outer surface 106b. As best viewed in Figure 1B, the base portion 106 is thicker in the chamber 112 than it is in the chamber114.

An outer sidewall 108 extends upwardly from the periphery of the base portion 106.

An inner sidewall 110 extends upwardly from the base portion 106, and defines and separates the two chambers 112 and 114 from one another. The first chamber 112 has a widthdimension"xl"and a length dimension"Y". The second chamber 114 has a widthdimension"x2"and a length dimension"Y".

A circuit module 102 is disposed in the second chamber 114 and is shown as having two electronic components 128a and 128b mounted to a printed circuit board (PCB) 120.

A first portion 130a.. 130d of the leadframe fingers extend from within the second chamber 114, through the outer sidewall 108 to the exterior of the encapsulation package 104, and a second portion 130e.. 130f of the leadframe fingers extend from within the second chamber 114, through the inner sidewall 110 to within the first chamber 112.

The PCB interconnection substrate 120 may have electronic components 128a and 128b mounted on its front surface. Conductive pads 126 on the PCB 120 are connected with bond wires 132 to inner ends of a plurality of elongateleadframe"fingers"130a.. 930f.

An electronic component 122 is disposed (mounted) in the first chamber 112.

Conductive pads 127 on the electronic component 122 are connected with bond wires 133 to inner ends of a plurality of elongateleadframe"fingers"130e.. 130f.

The circuit module 102 is an RF-transponder; the electronic component 122 is a pressure sensor; the electronic components 128a and 128b are integrated circuit devices; and the encapsulation package 104 may be mounted within a pneumatic tire.

The encapsulation package 104 is suitably formed from a thermoplastic material by a molding process, and the encapsulation package 104 may have dimensions comparable to (approximately equal to) those of the encapsulation packages described in the aforementionedcommonly-owned, copending PCT Patent Application No.

PCT/US98/07578.

For example, the height"H"of the outer and inner sidewalls 108 and 110 is suitably in the range of from approximately 3.0 mm to approximately 6.0 mm, such as5. 0 mm. Preferably, the inner sidewall 110 and those portions 108a, 108b and 108c of the outer sidewall 108 which, together with the inner sidewall 110 bound the chamber 112, are higher than the remaining portions 108d, 108e and108f of the outer sidewall 108.

The dimension"x2"of the second chamber 114 may be in the range of from approximately 10.0 mm to

approximately 40.0 mm, such as 20.0 mm.

Thedimension"xl"of the first chamber 112 may be approximately one-half the dimension"x2", such as approximately 10 mm. The dimension"X" (X = xl + x2) is suitably approximately 30 mm.

It should be clearly understood that the encapsulation package 104 is not limited to the dimensions set forth immediately hereinabove. The encapsulation package 104, and portions thereof, can be larger or smaller than described.

As mentioned hereinabove, the base portion 106 is thicker in the chamber 112 than it is in the chamber 114. However, as best viewed in Figure 1B, the outer surface 106b of the base portion 106 is generally planar.

In this embodiment, the inner surface 140 of the base portion within the chamber 112, whereupon the electronic component 122 is mounted, is at a distance"h3"above the outer surface 106b of the base portion 106. The inner surface of the base portion within the chamber 114 has a central area 142, whereupon the electronic module 102 is mounted, which is at a distance"h4"above the outer surface 106b of the base portion 106. The distance"h3"is greater than the distance"h4" (h3 > h4).

The inner surface of the base portion within the chamber 114 is stepped, so that an area 144 outside of the central area 142 is at a distance"h3"above the outer surface 106b of the base portion 106. In this manner, leadframe fingers (e. g.,130f) extending through the inner sidewall 110 lie in a plane on the inner surface portion 144 of the chamber 114 and the inner surface 140 of the chamber 112. In a similar manner, other portions of the inner surface of the base portion within the chamber, outside of the central area 142, can be stepped, so as to be at a distance"h3"above the outer surface 106b of the base portion 106.

In this example, a portion 146 of the inner surface of the base portion within the chamber 114 is stepped, so as to be a distance"h3"above the outer surface 106b of the base portion 106. In this manner, all of the leadframe fingers can be coplanar with one another.

As best viewed in Figure 1B, this results in the electronic component 122 being disposed at a higher level than the electronic module 102. Importantly, the increased thickness of the base portion in the chamber 112 provides a generally more rigid base for the electronic component 122 to be mounted upon. In the context of the electronic component 122 being a pressure sensor, such as has been described hereinabove, the benefits of the pressure sensor being mounted to a relatively rigid base are evident.

Figures1A and 1B also illustrate the concept that portions of the leadframe, in this case the leadframe fingers 130a.. 130d may extend to the exterior of the package so that the leadframe can be supported within a mold. In this example, the other leadframe fingers 130e and 130f which do not extend to the exterior of the package can be supported along with the leadframe fingers 130a.. 130d by an underlying insulating film (not shown), or by metallic webs or bridges (also not shown) which form part of the leadframe itself and which may later be excised from the leadframe. One of ordinary skill in the art to which the present invention most nearly pertains will readily understand the need to, and numerous ways available for, supporting the leadframe within a mold. Inasmuch as the techniques for doing so may vary from application-to-application, there is no need to further elaborate upon them in the description of the present invention.

The transponder module 100 illustrated and described with respect to Figure 1A and 1B is, for the purposes of the present invention, simply an example of a transponder module desired to be mounted within a pneumatic tire.

ANOTHER TRANSPONDER MODULE

Figures 2A and 2B, comparable to Figures 9C and 9D of the aforementioned commonly-owned, copending PCT Patent Application No. PCT/US98/07578, illustrate another exemplary transponder module 200 which is essentially a further packaging of the previously-described exemplary transponder module 100. The transponder module 100 shown without encapsulant, for illustrative clarity, it being understood that its two chambers (112 and 114) would be filled with potting compound (s).

An additional outer encapsulation package (housing) 254 is in the form of a simple cup-like structure, having a generally planar base portion 256. The base portion 256 is suitably circular, having a

diameter"P", and has an inner surface 256a and an outer surface 256b. An annular sidewall 258 having a height"Q"extends upwardly from the periphery of the base portion 256. In this manner, a cylindrical chamber 260 is formed. The height"Q" of the sidewall may be equal to, greater than, or (preferably) no greater than the height of the sidewalls of the transponder module 100.

The transponder module 100 is within the additional encapsulation package 254 with the outer surface (106b) of its base portion (106) being disposed against the inner surface 256a of the base portion 256 of the additional encapsulation package 254. Any suitable adhesive 262, such as a drop of cyanoacrylate ("super glue"), may be used to join the transponder module 100 to the additional encapsulation package 254.

Suitable dimensions for the additional encapsulation package 254 are:
The diameter"P"of the base portion 256 is in the range of from approximately 25.0 mm to approximately 60.0mm, such as approximately 32.0 mm ; The height"Q"of sidewall 258 is in the range of from approximately 3.0 mm to approximately 8.0 mm, such as approximately 4.0 mm ; and
The thickness"t"of the sidewall 258 is in the range of from approximately 0.3 mm to approximately 2.0 mm, such as approximately 1.0 mm.

It should be clearly understood that the additional encapsulation package 254 is not limited to the dimensions set forth immediately hereinabove. The additional encapsulation package 254, and portions thereof, can be larger or smaller than described, so long as the transponder module 100 fits within the circumference of the additional encapsulation package 254. The additional encapsulation package 254 is suitably molded from the same materials as the transponder encapsulation package (e. g., 104) described hereinabove.

The transponder module 200 illustrated and described with respect to Figure 2A and 2B is, for the purposes of the present invention, simply an example of a transponder module desired to be mounted within a pneumatic tire.

AN EXEMPLARY METHOD OF MOUNTING
A TRANSPONDER MODULE IN A PNEUMATIC TIRE
Figures 3A and 3B, comparable to Figures10A and10B of the aforementioned commonly-owned, copending PCT Patent Application No. PCT/US98/07578, illustrate an exemplary method of mounting the encapsulation package assembly within a pneumatic tire to provide tire pressure information to an externalreader/interrogator or to a driver of a vehicle riding on the tire.

Figure 3A shows the transponder module 200 being"sandwiched"between two thin sheets 302 and 304, such as rubber sheets, which are pressed to remove air bubbles from between the sheets and sealed around their edges. An adhesive 306 is disposed on the top (as viewed) surface of the sheet 302. In this manner, an exemplary transponder module within a"sandwich"patch 310 is ready to be mounted to an inside surface of a pneumatic tire.

Figure 3B shows the sandwich patch 310 of Figure 3A mounted within a pneumatic tire 312, on an inner surface thereof. An external reader/interrogator 320 having a wand 322 comprising an antenna 324 is suitably employed to poll (interrogate) the transponder circuit disposed within the pneumatic tire 312, and display data retrieved therefrom on a suitable readout 326 such as a liquid crystal display (LCD) panel. Using an external device to interact with a transponder device is well known and does not form a part of the present invention per se.

AN EXEMPLARY TRANSPONDER MODULE WITH AN INTERNAL ANTENNA
Figures 4A and 4B, corresponding to Figures5A and5B of the aforementioned commonly-owned U. S. Patent Application No. PCT/US98/07578, illustrate another embodiment of a transponder module 400 comprising an encapsulation package containing components of a transponder, including an antenna coil. The encapsulation package 404 suitably has a generally planar base portion 406 having an inner surface 406a and an outer surface 406b. An outer sidewall 408 extends upwardly (as best viewed in Figure 4B) from the periphery of the inner surface 406a of the base portion 406. An inner sidewall 410 (compare 110) extends upwardly (as best viewed in Figure 4B) from the inner surface 406a of the base portion 406 from a position which is within the periphery of the base portion 406. In this manner, two chambers are formed: an outer chamber 412 (compare 112) and an inner chamber 414 (compare 114) which can separately be filled with potting compound, or with two different potting compounds.

A circuit module 402 (compare 102) is disposed within the inner chamber 414 of the encapsulation package 404, and is mounted (as best viewed in Figure 4B) to the inner surface 406a of the base portion 406 with a suitable adhesive 418 (compare 118). The circuit module 402 may comprise a PCB interconnection substrate 420 (compare 120) with an electronic component 422 (compare 122) and another electronic component 428 (compare 128) disposed on its front surface, and the electronic component 422 may be a pressure sensor surrounded by a dam 424 to prevent the sensor from being covered when the inner chamber 414 is filled with potting compound.

Pads 426 (compare 126) of the PCB 420 are connected with bond wires 432 (compare 132) to inner ends of a plurality of elongateleadframe"fingers"430a.. 430h (compare130a.. 130f) which extend from within the inner chamber 414, through the inner sidewall 410 to within the outer chamber 412.

The circuit module 402 may be an RF-transponder, the electronic component 422 may be a pressure sensor component, the electronic component 428 may be an integrated circuit, and the encapsulation package 404 may be mounted within a pneumatic tire.

In this example, an antenna 450 is disposed within the outer chamber 412. The antenna 450 is formed by a length of insulated (e. g., enamel-coated) wire having two free ends 452 and 454 and wound into a coil having several turns and, optionally several layers.

As best viewed in Figure 4A, the two free ends 452 and 454 of the antenna wire 450 are shown as being connected to portions of the two leadframe fingers 430e and 430f, respectively, which are exposed within the outer chamber 412. These may be simple solder connections. Alternatively (not shown), the exposed portions of the leadframe fingers 430e and 430f can be formed with notches or the like to mechanically"capture"the free ends 452 and 454, respectively, of the antenna wire.

The transponder module 400 illustrated and described with respect to Figure 4A and 4B is, for the purposes of the present invention, simply an example of a transponder module desired to be mounted within a pneumatic tire.

AN EXEMPLARY TRANSPONDER MODULE WITH AN EXTERNAL ANTENNA

Figures 5A, 5B and5C, corresponding to Figures 6A, 6B and 6C of the aforementionedcommonly-owned U. S. Patent Application No. PCT/US98/07578, illustrate an application wherein an electronic device which is an RF transponder 500 (compare 400) which has an antenna component 550 which is external, rather than internal (compare 450) to the encapsulation package.

As in the previously-described embodiment (400), in this embodiment 500 the encapsulation package 504 suitably has a generally planar base portion 506 (compare 406) having an inner surface 506a (compare 406a) and an outer surface 506b (compare 406b).

An outer sidewall 508 (compare 408) extends upwardly (as best viewed in Figure 5B) from the periphery of the inner surface 506a of the base portion 506. An inner sidewall 510 (compare 410) extends upwardly (as best viewed in Figure 5B) from the inner surface 506a of the base portion 506 from a position which is within the periphery of the base portion 506. In this manner, two chambers are formed: an outer chamber 512 (compare 412) and an inner chamber 514 (compare 414) which can separately be filled with potting compound, or with two different potting compounds.

As in the previously-described embodiment, a circuit module 502 (compare 402) is disposed within the inner chamber 514 of the encapsulation package 504, and is mounted (as best viewed in Figure 5B) to the inner surface 506a of the base portion 506 with a suitable adhesive 518 (compare 418).

As in the previously-described embodiment, the circuit module 502 may comprise a PCB interconnection substrate 520 (compare 420) with an electronic component 522 (compare 422) and another electronic component 528 (compare 428) disposed on its front surface, and the electronic component 522 may be a pressure sensor surrounded by a dam 524 (compare 424) to prevent the sensor from being covered when the inner chamber 514 is filled with potting compound.

As in the previously-described embodiment, pads 526 (compare 426) of the PCB 520 are connected with bond wires 532 (compare 432) to inner ends of a plurality of elongateleadframe"fingers"530a.. 530h (compare 430a.. 430h) which extend from within the inner chamber 514, through the inner sidewall 510 to within the outer chamber 512.

Additionally, as best viewed in Figure 5A, two separate pads (terminals) 530i and 530j are illustrated. These pads 530i and 530j are suitably formed as part of the overall leadframe, the function of which is simply to provide terminals for connecting wires to one another.

As in the previously-described embodiment, the circuit module 502 may be an RFtransponder, the electronic component 522 may be a pressure sensor component, the electronic component 528 may be an integrated circuit, and the encapsulation package 504 may be mounted within a pneumatic tire.

In this embodiment of a transponder module 500, the antenna component 550 (shown principally as a dashed line) is external to the package 504, and is suitably formed as a length of wire having two free ends 552 and 554. Alternatively, the antenna component 550 may be a dipole-type antenna, having two separate lengths of wire (552 and 554).

As best viewed in Figure 5C, the free ends 552 and 554 of the external antenna component 550 pass through openings 556 and 558, respectively, in the outer sidewall 508 of the package 504 so that they can be attached to the terminals 530i and 530j, respectively, within the outer chamber 512 of the package 504.

An additional component 560 is optionally disposed within the outer chamber 512 and is suitably an impedance matching transformer having two primary leads 562 and 564 attached (e. g., soldered) to two of the leadframe fingers 530e and 530f, respectively, and having two secondary leads 566 and 568 attached (e. g., soldered) to the two additional terminals 530i and 530j, respectively.

As in the previously-described embodiment, certain ones of the leadframe fingers (e. g., 530e and 530f) and additional terminals (530i and 530j) can be formed with notches or the like to mechanically"capture"the various wires which are attached thereto.

The encapsulation package assembly 500 illustrated and described with respect to Figures 5A, 5B and5C is, for the purposes of the present invention, simply an example of a transponder module desired to be mounted within a pneumatic tire, in conjunction with an external antenna.

AN EMBODIMENT OF A PATCH FOR MOUNTING A TRANSPONDER MODULE

Figures 6A and 6B illustrate, in top plan and exploded cross-sectional views, respectively, a patch 600 for mounting a transponder module 602 on an inner surface of a pneumatic tire. As best viewed in Figure 6B, a typical pneumatic tire 630 includes an inner liner 604 and a ply 606 having a plurality of typically metal filaments (cords) 608 disposed therein. The inner liner 604 is representative of the inside surface of the overall tire, and the patch of the present invention, in its various embodiments disclosed herein, is not limited or restricted to any particular tire construction.

As illustrated in Figure 6B, the patch 600 of the present invention is suitably incorporated into a pneumatic tire in the course of the various tire plies being"laid up"on an outer surface 611 of a tire build drum 610. However, it should be understood that the patch of the present invention, in its various embodiments described herein, can also be mounted to an inner surface of a tire which has already been fabricated.

The transponder module 602, shown"generically"in the views of Figures 6A and 6B, is suitably any of the transponder modules described herein, for example the transponder module 400 shown and described with respect to Figure 4A, which has an internal antenna 450. However, it should be understood that the patch of the present invention, in its various embodiments described herein, is not limited to any particular transponder module, but rather is readily adapted to receive and mount a wide variety of transponder modules to an inside surface of a tire.

The patch 600 has two major external surfaces, a first external surface 612 and a second external surface 614 opposite the first external surface 612, and has a periphery 616.

The patch 600 has a length dimension"L", a width dimension"W", and a height dimension "H". It should be understood that the patch of the present invention, in its various embodiments described herein, is not limited to any particular dimensions other than being suitably sized and shaped to retain a transponder module for mounting to an inner surface of a pneumatic tire.

Preferably, the patch 600 tapers gradually from a maximum thickness (height) at its center to a minimum thickness at its periphery 616. The thickness of the patch 600 is the height dimension between the first

external surface 612 and the second external surface 614.

Preferably, the patch 600 is elongate and has a generally elliptical periphery 616, having an overall length dimension"L"which is larger than its overall width dimension"W".

Preferably, the patch 600 is relatively thin, having a maximum height dimension"H"which is a fraction of its width dimension"W".

An opening 620 is provided which extends into the patch 600 from the first external surface 612 thereof toward the second external surface 614 thereof. Preferably, the opening 620 is located substantially centrally both lengthwise and widthwise, in the patch 600. As best viewed in Figure 6B, the opening 620 extends to a cavity 622 which is centrally located within the body of the patch 600. The cavity 622 is somewhat larger (in the lengthwise and widthwise dimensions) than the opening, resulting in there being an annular lip 624 disposed at the"entrance"to the opening 620.

The cavity 622 is sized and shaped to be approximately the same size and shape as, or only somewhat larger than the transponder module 602 to be retained by the patch 600, and the annular lip 624 is sized to be somewhat smaller in corresponding dimension than the transponder module 602 so that the transponder module 602 may be inserted through the opening 620 into the cavity 622 by deflecting the annular lip 624, thereafter to be retained within the cavity 622 by the annular lip 624.

For example, the transponder module 602 may be in the general form of a disc having a diameter of approximately25-60 mm, such as approximately32 mm, and having a thickness (height) of approximately 3-8mm, such as approximately 5 mm, in which case the cavity 622 may also suitably be in the general form of a disc, having a diameter comparable (approximately equal) to the diameter of the transponder module and a height comparable (approximately equal) to the thickness of the transponder module 602. The patch opening 620 may have a diameter which is approximately14 mm, such as approximately 2 mm, less than the diameter of the cavity 622 or the transponder module 602. In this way, the annular lip 624 is formed in a manner intended to retain the transponder module 602 within the cavity 622.

The annular lip 624 may be provided with one or more, such as two diametricallyopposed, or three evenly-spaced (as shown), slots 626 in order to facilitate manipulating (deflecting) the annular lip 624 for inserting the transponder module 602 past the lip 624 into the cavity 622, as well as for removing (if necessary) the transponder module 602 from the cavity 622. It is within the scope of the invention that the annular lip 624 may be formed with features other than slots (626), such as serrations, to facilitate transponder insertion or removal.

It is a feature of the present invention that the transponder module 602 can be inserted into the patch 600 either before the patch 600 is affixed to an inside surface of a pneumatic tire, or after the patch 600 is affixed to an inside surface of the tire. And, as mentioned hereinabove, the patch 600 can be affixed to an inside surface of a pneumatic tire either before the tire is built or after the tire is built.

The patch 600 is suitably formed of a resilient material such as halobutyl rubber, so that when a vehicle upon which the tire is mounted is operating (i. e., driving), the patch 600 can flex in unison with the tire within which it is mounted. It should be understood that the patch of the present invention, in its various embodiments described herein, is not limited to any particular one resilient material. A person having ordinary skill in the art to which the invention most nearly pertains will appreciate that the material selected for the patch should not be incompatible with the material of the tire itself, and should be capable of withstanding the ambient temperatures, pressures, and dynamic forces present within a tire. It is also within the scope of the present invention that the patch can be made of two or more materials, layered, and the like. Preferably, in the case of the patch being affixed to an inside surface of a tire in the process of building the tire, portions or all of the patch are suitably semi-cured.

As mentioned above, an advantage of having an opening 620 leading from an external surface 612 of the patch 600 to the cavity 622 within the patch 600 is that the transponder module 602 can be inserted into the patch 600 either before or after the patch 600 is affixed to an inside surface of a pneumatic tire. Another advantage of having the opening 620 is for facilitating removal of the transponder module 602, such as for repair or replacement. Another advantage of having the opening 620 is that the transponder module 602 is accessible while contained within the patch 600, such as for battery replacement, such as is described with respect to the next embodiment. Another advantage of having the opening 620 is that at least a potion of the transponder module 602 is exposed to the ambient environment within the pneumatic

tire, such as for sensing air pressure.

Typical dimensions for the transponder module 602, and corresponding typical dimensions for the cavity 622 of the patch 600 have been set forth hereinabove. Typical overall dimensions for the patch 600 are: A length"L"which is approximately 60-150 mm, such as approximately80 mm, greater than the diameter of the transponder module 602; A width"W"which is approximately 30-66 mm, such as approximately38 mm, greater than the diameter of the transponder module 602; and A height"H"which is approximately5-20 mm, such as approximately9 mm, greater than the thickness of the transponder module 602.

An advantage to having the thickness (height"H") of the patch 600 as small as possible, and then tapering gradually to nearly zero thickness at its periphery 616, is so that in the process of laying up a tire on a build drum 610, the filaments 608 will maintain their typically uniform spacing from one another or, in other words, won't"creep"apart from or toward one another.

It is within the scope of this invention that a recess (not shown) can be incorporated into the drum 610 within which the patch 600 can be disposed, so that the external surface 614 of the patch is substantially contiguous with the external surface of the build drum 611.

Figure 6C illustrates, in cross-sectional view comparable to that of Figure 6B, an alternate transponder module 602a contained within the patch 600. For purposes of describing this embodiment of the patch 600, all other aspects of the patch 600 can be considered to be similar to those described hereinabove.

The transponder module 602a is disposed within the cavity of the patch 600 which, in turn, is mounted to an inner surface (not shown in this figure) of a pneumatic tire. Herein it can be seen that an additional component 630, such as a battery pack, can be associated with (e. g., plugged into) the transponder module 602a. Although shown as extending out of the opening 620, the additional component 630 may be sized (i. e., in the height dimension) so that it does not extend out of the opening 620.

A benefit of the opening 620 in the patch 600 is that objects which are too tall to be built into a tire may be added to a finished tire when the patch of this invention has been built-in or added to the inner surface of the tire.

AN EMBODIMENT OF A PATCH WHICH CONNECTS TO AN ANTENNA

Thus far there has been described a patch 600 suitable for retaining a transponder module 602 or 602a, and for mounting the transponder module to an inner surface 604 of a pneumatic tire. The patch 600 described hereinabove is made of a resilient material that is intended (and preferably selected) not to attenuate any radio frequency (RF) transmissions either into or out of the transponder module. Nor, on the other hand, is it anticipated that the patch 600 described hereinabove would do anything to directly aid in or augment the transmission or reception of RF signals by the transponder module.

Figures 7A, 7B, 7C and 7D illustrate an alternate embodiment of a patch 700 which, for purposes of this description, is generally comparable in overall size, shape and material to the previously-described patch 600, but which has additional components incorporated therein for facilitating the transmission or reception of RF signals by the transponder module 702 (compare 602) retained within the patch. In these figures, the lip 724 (compare 624) is illustrated without slots (see 626) or serrations.

In this embodiment, an antenna 740 having two end portions 742 and 744 is disposed within the tire (not shown), such as about an inner circumference of the tire on an inner surface thereof. The antenna 740 may simply be an elongate conductor, such as a wire, in a loop having two ends (hence, two end portions 742 and 744). Alternately, the antenna 740 may be a dipole antenna with two separate conductors, each conductor having a respective end portion 742 and 744, respectively, extending to within the patch.

A coil 750, comprising at least a few turns of wire and having two ends 752 and 754 is disposed within the body of the patch 700 closely adjacent and surrounding the cavity 722. The coil 750, as will become evident, serves as one"winding" (coupling loop) of a coupling (e. g., input/output) transformer.

The end portion 742 of the antenna 740 extends from outside the patch 700, through the bottom surface 714 thereof, to within the body of the patch 700 where it is connected to the end 752 of the coil 750. In a similar manner, the end portion 744 of the antenna 740 extends from outside the patch 700, through the bottom surface 714 thereof, to within the body of the patch 700 where it is connected to the end 754 of the coil 750.

As shown in Figure 7C, a transponder module 702 is retained within the patch 700, generally in the manner that the transponder module 602 was retained in the patch 600, described hereinabove. Namely, the transponder module 702 is inserted into the cavity 722 (compare 622) of the patch 700 past an annular lip 724 (compare 624) through an opening 720 (compare 620) in the top surface 712 (compare 612) of the patch 700.

In this example, the transponder module 702 is provided with an internal input/output coil 760, rather than an antenna, which is preferably disposed adjacent the circumferential periphery of the transponder module 702. The transponder module 400 of
Figures 4A and 4B exemplifies such a transponder module 702, in which case the antenna coil 450 would serve as the input/output coil 760. As mentioned hereinabove, the coil 750 serves as one"winding"of a coupling transformer. The coil 760 is preferably concentric with the coil 750, and located within no more than a few millimeters therefrom, and serves as another winding (coupling loop) of the coupling transformer. In this manner, the antenna 740 may be efficiently coupled ("transformer-coupled") to the coil 760 within the transponder module 702. The function of the"coupling transformer"formed by the two coupling coils 750 and 760 is comparable to that of the transformer 560 described hereinabove with respect to Figures 5A and 5B.

Preferably, the two end portions 742 and 744 of the antenna 740 enter the body of the patch 700 at diametrically opposed positions on the patch 700. It is within the scope of this invention that the end portions 742 and 744 of the antenna 740 enter the body of the patch 700 at other than diametrically opposed positions, and other than through the bottom surface 714 as described hereinabove. For example, Figure 7D shows an alternate embodiment of the patch 700'wherein the end portions 742'and 744' (compare 742 and 744) of the antenna 740' (compare 740) enter the patch 700' (compare 700) through the top surface 712' (compare 712), preferably at points on the periphery of the tapered edge of the patch 700'. The coupling coil 750'corresponds to the coupling coil 750 of Figure 7C.

MOLDING THE PATCH (ES)
There has thus been described patches (e. g. 600,700) suitable for retaining transponder modules (e. g. 602,702). The latter patch embodiment 700 is suitable for use with an antenna 740 which is external to the transponder module, and also incorporates a coil 750 serving as a winding of a transformer for coupling to a corresponding coil 760 of the transponder module. It is contemplated that the coil 750 is a few (e. g., 2-1/2) turns of wire which are molded (or cast) into the body of the patch 700.

Molding is a well known process whereby materials in a fluid or liquid state are injected or otherwise caused to fill a cavity (or multiple, typically interconnected cavities) in a mold, then permitted (or caused, such as by the application of heat and/or pressure) to solidify (e. g., cure or otherwise harden or become less fluid), after which the mold is removed from around the solidified object (or the solidified object is removed from the mold). A typical mold has two halves which come together in clamshell-type manner to define a closed space within which material to be molded into a molded part is disposed.

The interior surfaces of the mold halves typically define the exterior surfaces of the molded part. In order to incorporate a"foreign object"such as the aforementioned coil 750 into the body of the patch 700, it is desirable to prefabricate the coil 750 and support it in any suitable manner within the cavity of the mold. It should be understood that if the antenna wire end portions (e. g., 742 and 744) are to extend outside the mold, appropriate grooves or holes (not shown) should be provided at the outside edges of the mold halves.

Figure 8 illustrates a mold 800 for molding a patch comparable to the previouslydescribed patch 600. The mold 800 is shown as having two halves, an upper mold half 802 and a lower mold half 804. The upper mold half 802 has an interior surface 806 which is shaped to correspond to a surface of a patch, for example the upper external surface 612 of the patch 600. The lower mold half 804 has an interior surface 808 which is shaped to correspond to another surface of a patch, for example the lower external surface 614 of the patch 600. More particularly, the interior surface 808 of the lower mold half is generally planar. The interior surface 806 of the upper mold half is contoured, to impart the desired taper to the resulting molded part (e. g., patch 600).

A mandrel810, which may be integral with the upper mold half 802, extends (projects) from the interior surface 806 of the upper mold half 802 toward the interior surface 808 of the lower mold half 804 at a location on the interior surface 806 of the upper mold half 802 whereat it is desired to form the opening (e.

g., 620), the annular lip (e. g., 624) and the cavity (e. g., 622) in the patch (e. g., 600) to be molded within the mold 800.

Although not shown as such, one of ordinary skill in the art to which the present invention most nearly pertains will understand that the mandrel 810 may be, and may preferably be, a "collapsible"mandrel. A collapsible mandrel is a mandrel which can be collapsed, therefore reduced in size, to permit it to be withdrawn from or through a space or opening in a molded part which has a smaller dimension than the overall mandrel.

A portion 812 of the mandrel 810 is sized and shaped to generally define the resulting size and shape of the cavity (e. g., 622) of the to-be-molded patch (e. g., 600) and, utilizing the example of a cylindrical disc-like cavity set forth hereinabove, is in the general form of a disc having a diameter corresponding to the diameter of the desired cavity (e. g., 622) and a thickness (height) corresponding to the height of the desired cavity (e. g., 622).

One skilled in the art to which the invention most nearly pertains will understand that, depending on the materials and processes utilized for molding the molded part (e. g., 600), the mold elements need to be sized to allow for material shrinkage, warpage and the like.

When the mold halves 802 and 804 are brought together, as indicated by the dashed lines in the figure, their interior surfaces 806 and 808 form a cavity into which material for the desired molded part can be introduced, via a suitable orifice or gate (not shown). The material is then permitted (or caused) to harden or solidify (including only partially curing); the mold halves 802 and 804 are separated; the molded part is removed; and, if necessary, the molded part is post-processed (e. g., such as removing flashing,de-junking the finished part, and the like).

It is within the scope of this invention that additional features can be incorporated into the mold halves 802 and 804, such as for forming the slots 626 (or serration, not shown) in the annular lip 624 described hereinabove with respect to Figures 6A and 6B.

Figure 8A illustrates an embodiment of an upper mold half 820 suitable for molding a patch comparable to the previously-described patch 700 having a coil 740 embedded therein. As in the previously-described embodiment of an upper mold half 802, in this embodiment a mandrel 822 (compare 810), which may be integral with the upper mold half 820 (compare 802), extends from the interior surface 824 (compare 806) of the upper mold half 820, and has a portion 826 (compare 812) corresponding to the desired shape of a cavity (e. g., 722), of the resulting patch (e. g., 700). As in the previous example, the mandrel 822 may be a"collapsible"mandrel.

An outer surface 828 of thecavity-defining portion 826 of the mandrel 822 is formed in a manner suitable to have a coil of wire (compare 750) wound around it, for example within a groove 830 spiraling around the outer surface 828 of thecavity-defining portion 826 of the mandrel 822. To accommodate the ends of this coil of wire extending outside the mold, suitable grooves (not shown) may be cut into the inside surface (s) of either or both halves of the mold.

Figure 8B illustrates a patch 850 resulting from the molding process described with respect to Figure 8A. Herein it can be seen that the patch has a first external surface 852 (compare 712), a second external surface 854 (compare 714), an opening 856 (compare 720) in the first external surface 852 leading past an annular lip 858 (compare 724) to a cavity 860 (compare 722) within the body of the patch 850. An antenna wire 862 (compare 740) has a first portion 864 (compare 742) entering the patch 850 from the second external surface 854 thereof; has a second portion 866 (compare 750) transitioning from the first portion at point 874 (compare 752), and which was wound around the outer surface 828 of thecavity-defining portion 826 of the mandrel 822; and has a third portion 868 (compare 744) transitioning from the second portion at point 878 (compare 754), and which exits the patch 850 from the second external surface 854 thereof. In this manner, an integral coupling coil is formed by the second portion 866 of the wire 862 which is disposed at a periphery of the cavity 860 so as to be as close as possible (for effective coupling) to a corresponding coupling coil disposed within (or wound about the peripheryof) a transponder module (compare 702) disposed within the cavity 860 (compare 722).

MOLDING A BOBBIN INTO THE PATCH

Evidently, in order to mold the patch 850 using the upper mold half 820 and winding a wire around the periphery 828 of thecavity-defining portion 826 of the mandrel 822, may require that the mandrel be

collapsible.

Figure 9A illustrates a mold 900 for molding a patch 950 comparable to the previously-described patch 850. The mold 900 is shown as having two halves, an upper mold half 902 and a lower mold half 904. The upper mold half 902 has an interior surface 906 which is shaped to correspond to a surface of a patch being molded (not shown), for example the upper external surface 712 of the patch 700. The lower mold half 904 has an interior surface 908 which is shaped to correspond to another surface of the patch being molded, for example the lower external surface 714 of the patch 700. More particularly, the interior surface 908 of the lower mold half is generally planar. The interior surface 906 of the upper mold half is contoured, to impart the desired taper to the resulting molded part (e. g., patch 700). Also, as described hereinabove for the mold in Figure 8, suitable grooves (not shown) may be cut into the inside surface (s) 906/904 of either or both halves of the mold 902/904 in order to accommodate antenna wires 940 as they exit the mold.

A mandrel 922, which may be integral with the upper mold half 902, extends (projects) from the interior surface 906 of the upper mold half 902 toward the interior surface 908 of the lower mold half 904 at a location on the interior surface 906 of the upper mold half 902 whereat it is desired to form the opening (e. g., 722), the annular lip (e. g., 724) and the cavity (e. g., 720) in the patch (e. g., 700) to be molded within the mold 900.

A portion 926 of the mandrel 922 is sized and shaped to generally define the resulting size and shape of the cavity (e. g., 722) of the to-be-molded patch (e. g., 700) and, utilizing the example of a disc-like cavity set forth hereinabove, is in the general form of a disc having a diameter corresponding to the diameter of the desired cavity (e. g., 722) and a thickness (height) corresponding to the height of the desired cavity (e. g., 722). It should be understood that the mandrel 922 is shown without any features for imparting slots (see 626) to the patch being molded.

When the mold halves 902 and 904 are brought together, as indicated by the dashed lines in the figure, their interior surfaces 906 and 908 form a cavity into which material for the desired molded part can be introduced, via a suitable orifice or gate (not shown). The material is then permitted (or caused) to harden or solidify (including only partially curing); the mold halves 902 and 904 are separated; the molded part is removed; and, if desired or necessary, the molded part is post-processed.

In this embodiment, rather than forming an outer surface 928 (compare 828) of the cavity-defining portion 926 of the mandrel 922 with a groove (830) for winding a wire around the mandrel, a separate bobbin (or spool) element 930 is employed.

The bobbin element 930 is an annulus, having a generally cylindrical interior surface 932, and which is sized to fit about the outer surface 928 of the mandrel 922. The bobbin 930 has an outer surface 934 which is formed with a spiral groove 936 (compare 830) for having a second portion 938 (compare 866) of a wire 940 (compare 862) wound around the bobbin 930. End portions 942 (compare 864) and 944 (compare 868) of the wire exit the mold to become the first and third portions of the antenna wire (s) 940 (compare 862) in the manner described hereinabove.

In order to mold a patch, the bobbin 930, with wire 940 wound thereupon, is slipped into place on the outer surface 928 of the mandrel 922; the wire end portions 942 and 944 are placed in grooves (not shown) allowing them to exit the mold 900 between the mold halves 902 and 904; the mold halves 902 and 904 are brought together; and the cavity defined by the inner surfaces 906 and 908 of the mold halves 902 and'904, respectively, is filled with material suitable to mold a patch. A resulting patch 950 (compare 850) having a bobbin-wound coil disposed within the body of the patch is illustrated in Figure 9B.

Either or both of the interior surface 932 of the bobbin 930 and/or the outer surface 928 of the mandrel 922 may be tapered, so as to have a slight (e. g., 1-3 degree)"draft angle"which facilitates the mold halves to be readily separated after molding a patch.

Figure 9B further illustrates, a transponder module 951 (compare 702) retained within the patch 950 (compare 700), generally in the manner that the transponder module 702 was retained in the patch 700, described hereinabove. Namely, the transponder module 951 is inserted into the cavity 960 of the patch 950 past an annular lip 958 through an opening 956 in the top surface 952 of the patch 950. As in Figure 7C, the transponder module 951 (compare 702) is provided with an internal input/output (coupling) coil 953 (compare 760), which is preferably disposed adjacent the circumferential periphery of the transponder

module 951. As mentioned hereinabove, the coil 938 (compare 750) serves as one"winding"of a coupling transformer. The coil 953 (compare 760) is preferably concentric with the coil 938, and located within no more than a few millimeters therefrom, and serves as another winding (coupling loop) of the coupling transformer. In this manner, the antenna 940 (compare 740) may be efficiently coupled to the coil 953 (compare 760) within the transponder module 951 (compare 702).

Figure 9C illustrates a patch 980 which is an alternate embodiment of the patch 950, wherein the coil of wire 968 (compare 938) is disposed on a bobbin 961 (compare 930) which is smaller in diameter than 930, and has been molded into the patch at a location between the patch's bottom surface 984 (compare 954) and the bottom surface of the cavity 990 (compare 960), underneath the cavity 990. An antenna 970 (compare 940) has two end portions 972 and 974 (compare 942 and 944) entering the patch 980. As in Figure 9B, the transponder module 951 is shown disposed in the cavity 990. The bobbin 961 is sized so that the turns of wire 968 form a circle of approximately the same outside diameter as the turns of wire 953 in the transponder 951. In this manner, when a transponder (e. g., 951) is placed in a patch (e. g., 980), the two coupling coils (953 and 968, respectively) will be concentric and closely adjacent, and will therefore provide efficient transformer-type coupling of energy.

* Although the corresponding mold halves for the patch 980 are not illustrated, it should be evident that the mold cavity between surfaces 906 and 908 would have to be suitably larger to accommodate the extra space needed for the bobbin 961 which would be placed on the bottom mold surface 908 underneath the mandrel 922 which is used to form the cavity 990, lip 988, and opening 986. There may be a groove in, or fingers protruding from, the bottom mold surface 908, either of which would be intended to hold the bobbin 961 in position during the molding process.

One of ordinary skill in the art to which the present invention most nearly pertains will readily understand that other variations on the themes presented hereinabove will accomplish the same objectives (of coupling an antenna wire in a patch to a transponder module contained within that patch), and can be considered within the scope of this invention. For example, the bobbins 961 and 930 could have an annular recess (as in
Figure 9C) instead of a spiral groove (as in Figure 9B) to contain and shape the coil of wire (968 and 938 respectively). It would also be reasonable to pre-form the coil of wire 968/938 without a permanent bobbin, perhaps holding its shape with paper or plastic nonconductive tape. In addition, as mentioned hereinabove, the antenna 940 or 970 may either exit from the patch through the bottom surface (e. g. 954 as in Figure 9B), or through the patch's top surface (e. g. 982 as in Figure 9C).

ALTERNATE EMBODIMENTS OF TRANSPONDER MODULES
A number of transponder modules, suitable for being retained within a cavity of a patch which is ultimately mounted to an interior surface of a pneumatic tire have been described hereinabove. As mentioned, a transponder module may advantageously include a coil of wire (e. g., 760) comparable to the antenna 450 for coupling RF energy to and from a coil (e. g., 750) embedded within the patch.

Figure10A illustrates a transponder module 1000, comparable to the transponder module 400 described hereinabove, but which has a coupling coil 1004 disposed on a bobbin-like external surface (wall) 1002 (compare 408) of the transponder module 1000, rather than being disposed within the transponder module 1000. The coupling coil 1004 is shown"broken", or partially in plan view and partially in cross-section, as"nesting"in a recess 1006 in the external wall 1002 of the transponder module 1000. In this manner, the transponder module coupling coil 1004 can be closely adjacent a coupling coil (e. g., 750, 866,938) disposed within the body of a patch (e. g., 700,850,950, respectively).

The coupling coil 1004 may have two ends (not shown) which extend through corresponding openings (not shown, compare 556 and 558) in the external wall 1002 of the transponder module 1000, suitably in a manner as described hereinabove with respect to the wires 552 and 554 extending through the external wall 508 of the transponder module 500.

Figure10B illustrates an alternate embodiment 1020 of a transponder module, comparable to the transponder module 1000 described hereinabove, in that it has a coupling coil 1024 (compare 1004) disposed on a bobbin-like external surface (wall) 1022 (compare 1002) of the transponder module 1020. In this embodiment, the transponder module 1020 also has a coupling coil 1026 disposed on the inside of the external wall 1022. The interior coupling coil 1026 is comparable to the previously-described antenna 450 shown and described with respect to Figure 4B. A first coupling of RF energy occurs between the coupling

coil 1026 on the interior surface of the wall 1022 and the coupling coil 1024 on the exterior surface of the wall 1022.

The transponder module 1020 is suitably disposed in a cavity of a patch, such as has been described hereinabove, so that the coupling coil 1024 is closely adjacent and RFcoupled with a corresponding coupling coil (e. g., 750,866,938) disposed within the body of a patch (e. g., 700,850,950, respectively). In this"double-coupled"embodiment of a transponder module 1020, it is not necessary that ends of the external coupling coil 1024 extend through corresponding openings (not shown, compare 556 and 558) in the external wall 1022 of the transponder module 1020.

ANOTHER TRANSPONDER/PATCH EMBODIMENT

Patches having coupling coils embedded therein have been described hereinabove as a means to inductively connect an antenna in the tire to a transponder module retained within the patch. There is now described an embodiment of a patch and transducer that is modified to have"hard-wired", yet removable connections between an antenna in the tire and a transponder module retained within the patch.

Figure 11 illustrates an embodiment of a patch 1100 for retaining a transponder module 1102.

The patch 1100 is similar in size, shape and materials to any of the patches (e. g., 600) described hereinabove in that it has two major external surfaces, a first external surface 1112 (compare 612), a second external surface 1114 (compare 614) opposite the first external surface 1112, a periphery 1116 (compare 616), and is tapered from a maximum thickness (height) at its center to a minimum thickness at its periphery 1116.

A central opening 1120 (compare 620) is provided which extends into the patch 1100 from the first external surface 1112 thereof toward the second external surface 1114 thereof.

The opening 1120 extends to a cavity 1122 (compare 622) which is centrally located within the body of the patch 1100. The cavity 1122 is somewhat wider than the opening, resulting in there being an annular lip 1124 (compare 624) disposed at the"entrance"to the opening 1120. The cavity 1122 is sized and shaped to be approximately the same size and shape as, or only somewhat larger in width and height than the transponder module 1102 (compare 602).

The patch 1100 is similar to other patches (e. g., 700) described hereinabove in that an antenna 1140 (compare 740) has two end portions 1142 and 1144 (compare 742 and 744) that enter into the body of the patch 1100. However, rather than terminating in a coupling coil (e. g., 750), the two end portions 1142 and 1144 terminate in electrical terminals which are contact pads 1152 and 1154 respectively, disposed on an interior (e. g., bottom) surface 1126 of the cavity 1122.

The transponder module 1102 is similar to other transponder modules (e. g., 200) described hereinabove in that appropriate (for performing the desired transponder functions) electronic components are disposed within a housing 1104 (compare 254).

In this embodiment of a transponder module 1102, rather than the transponder module having its own antenna (e. g., 450), or a coupling coil (e. g., 760) inductively coupling to a corresponding coupling coil (e. g., 750) within the patch,"hard-wired", yet removable (dis-connectable) connections are made between the antenna 1140 and the transponder module 1102, in the following manner.

As described hereinabove, the electronic components (e. g., 102,122) disposed within the transponder housing are suitably interconnected with one another via a leadframe (e. g., 130) having a plurality of leadframe fingers, some of which suitably extend from the interior of the transponder module housing to the exterior of the transponder module housing.

In this embodiment of a transponder module 1102, selected ones 1132 and 1134 of a plurality of leadframe fingers extend from within the interior of the transponder module housing 1104 to the exterior of the transponder module housing 1104 and, as illustrated, may be formed so as to lay flat on an external surface of the transponder module 1102, such as on a bottom surface 1106 (compare 106b) thereof. The portions of the leadframe fingers 1132 and 1134 disposed on the bottom surface 1106 of the housing, are positioned to align with the contact pads 1152 and 1154 disposed on the bottom surface 1126 of the cavity 1122. In this manner, when the transponder module 1102 is inserted into the cavity 1122 of the patch 1100, electrical connections can be effected between the leadframe fingers 1132 and 1134 and the

contact pads 1152 and 1154, respectively, so as to electrically connect the antenna 1140 to the transponder module 1102.

In order to ensure contact between the transponder leadframe fingers 1132/1134 and the patch contact pads 1152/1154, the fingers or the pads may be extended in an arc-like manner around the surfaces they lie on. There may also be notches, protrusions, or other irregularities in the inside surface of the cavity 1122 which correspond to mating irregularities in the outside surface of the transponder 1102. These mating irregularities would allow for registration of the transponder to the cavity, thereby holding the two parts in the an orientation which maintains contact between the fingers 1132/1134 and their corresponding contact pads 1152/1154. These features are not shown in Figure 11, but should be readily apparent to one practiced in the art which most nearly pertains to the present invention.

Figure 11A illustrates an alternate embodiment of the concepts presented in Figure 11, wherein two end portions 1142'and 1144' (compare 1142 and 1144) of an antenna 1140' (compare 1140) terminate in electrical terminals which are contact plugs 1152'and 1154' (compare 1152 and 1154).The contact plugs 1152'/1154'are disposed on an interior (e. g., bottom) surface 1126' (compare 1126) of the cavity 1122' (compare 1122). The contact plugs1152'/1154' (compare 1152/1554) may be formed in the shape of prongs, such as flat"male"spade prongs or bullet-like pins", and portions of the leadframe fingers1132'/1134' (compare 1132/1134) may be formed as corresponding (mating)"female receptacle contacts"which mate with respective ones of the prongs1152'/1154'. In this manner, when the transponder 1102'is properly inserted in the cavity 1122'of the patch 1100', the prongs1152'/1154'would"plug in"to their corresponding receptacles1132'/1134'in much the same way that an electrical cord end plugs into a wall receptacle.

The design of such plug/receptacle pairs is well known in the electrical industry, and the claim of this invention lies in the area of its application to patches and mating transponder modules such as are illustrated in Figure 11A. It is within the scope of this invention that the plug/receptacle pairs could use different materials (e. g., spring steel or conductive rubber) and could take different forms, such as reversing the contacts to make 1132'and/or 1134'as plug prongs and making 1152'and/or 1154'as their mating receptacle contacts.

Although only two pads 1152/1154 or two prongs 1152'/1154'are illustrated in Figures 11 and 11A, it should be understood that two or more than two pads or prongs may be provided, and they may be disposed symmetrically or asymmetrically on the surface 1126,1126'of the cavity 1122,1122', respectively.

ANTENNA DESIGN CONSIDERATIONS

In a number of embodiments described hereinabove, an antenna (e. g., 740,1140) has been briefly described as having two end portions (e. g., 742/744,1142/1144) which enter the body of the patch (e. g., 700,1100) and which are either connected to a coupling coil (e. g., 750) surrounding the transponder module-receiving cavity (e. g., 722) within the body of the patch (e. g., 700), or which are connected to contact pads (e. g., 1152/1154) on a surface of the transponder module receiving cavity (e. g., 1122) within the body of the patch (e. g., 1100).

It should be clearly understood that any antenna having two end portions, whether or not the antenna is a loop antenna (for example, the antenna could be a dipole antenna) is suitable for use with the patch embodiments described herein. Additionally, the antenna may be either attached to the inside surface of the tire, or embedded within the carcass of the tire.

For example, as discussed hereinabove, PCT Patent Application No.

PCT/US90/01754 discloses a loop-type antenna which comprises a receiver/transmitter coil having one or more loops of wire strategically placed along the sidewall or in proximity to the tread face of the tire, as well as various possible locations for an antenna/coil which is embedded within the carcass of the tire. As disclosed therein, theantenna/coil may be formed of one or more turns of insulated wire, or bare wire separated by insulating rubber in the manufacturing process. Acceptable materials for the wire are stated as including steel, aluminum, copper or other electrically conducting wire. As disclosed therein, the wire diameter is not generally considered critical for operation as an antenna for a transponder. For durability, stranded steel wire consisting of multiple strands of fine wire is preferred. Other wire options available include ribbon cable, flexible circuits, conductive film, conductive rubber, etc. The type of wire and number of loops in the antenna/coil is a function of the anticipated environment of the tire use and the preferred

distance of interrogator communication. It is proposed therein that the greater the number of loops of the transponder's antenna/coil, the greater the distance ofsuccessful interrogation of a given tire transponder.

There are now described a number of embodiments of antennas which are particularly well-suited to be used in conjunction with the patches described herein.

ANTENNA EMBODIMENTS

Figures 12A and 12B illustrate an embodiment of an antenna 1200 extending about the entire inner surface 1202 (compare 314,604) of a pneumatic tire 1204 (compare 312).

The antenna 1200 is essentially an elongate loop of wire. One segment or end portion 1208 (compare 742) of the antenna 1200 terminates at a coupling coil or contact pad (neither of which are shown in these figures) within a patch 1210 (compare 700) in which there is a transponder module (e. g., 702). The other segment or end portion 1212 (compare 744) of the antenna 1200 terminates in like manner at a coupling coil or contact pad within the patch 1210. The antenna 1200 is affixed in any suitable manner to the inner surface 1202 of the tire 1204, and may optionally be embedded (fully or partially) under the inner surface 1202 of the tire 1204 during tire manufacturing.

Preferably, the antenna 1200 is formed as an elongated spiral of wire, or helix.. For example, referring to Figure 12C, a length of wire 1220 having a diameter (gauge)"d"of between approximately 0.15mm and approximately 0.30 mm can be coiled into a helix with an overall diameter"D"of between approximately 1.0 mm and approximately 2.0 mm.

Such a helical antenna can be fabricated to have an initial (starting) pitch"P" (as measured from one coil turn to the next) of between approximately ONE or TWO wire diameters (P = between ld and 2d), and can stretch out in length to several, such as FIVE, times its initial length.

The wire 1220 is, of course, electrically conductive, and is suitably brass-plated high-tensile strength steel which exhibits good mechanical strength and resistance to corrosion when placed in the environment of the interior of a pneumatic tire. Alternatively, the wire 1220 can be nickel or gold plated.

It is within the scope of the invention that the antenna 1200 can be formed in two segments which are two separate lengths of wire, each segment having a first end portion extending from within the patch 1210, and each length of wire extending at least partially (e. g., approximately half-way) around the circumference of the inner surface 1202 of the tire 1204. Two such lengths of wire can be joined in any suitable manner (such as by wrapping or soldering) at their second ends opposite to the patch, to form a complete loop antenna extending around the entire circumference of the inner surface 1202 of the tire 1204. Alternatively, the free ends could be left unattached, thereby forming a dipole antenna with poles 1208 and 1210, disposed about the circumference of the inner surface 1202 of the tire 1204. As has been mentioned hereinabove, the antennas described as extending around the circumference of the inner surface of the tire could be either attached (mounted) to the inner surface of the tire or embedded in the tire carcass under the inner surface.

EMBODIMENTS OF ANTENNAS AND CORRESPONDING PATCHES

As discussed hereinabove, an antenna may suitably be formed as two individual lengths of wire, each emanating from a patch having a transponder module therein, each spanning approximately one-half the circumference of the inner surface of the tire, and either joined to one another at their opposite ends to form a complete loop antenna, or left unconnected so that they form a dipole antenna.

Figure 13A illustrates an embodiment of component 1300 of an antenna comprising an elongate wire 1302, which is preferably a helical coiled wire comparable to the aforementioned helical wire 1220, embedded in a strip 1304 of rubber material which is suitable for bonding to an inside surface of a pneumatic tire. The strip 1304 of rubber material has a one end 1306 and an opposite end 1308, and may either be electrically insulating (non-conductive) or an electrically conductive composition. The strip 1304 is shown as having a tapered profile, but it should be understood, and it is within the scope of the invention, that its cross-section could be rectangular, semicircular, or any shape preferably having at least one flat side suitable for bonding to a substantially flat inside surface of a pneumatic tire. Alternatively, for antennas which may be embedded in the tire carcass, the strip 1304 could have any cross-sectional shape, but is preferably round, with the diameter of the rubber material only slightly larger than the diameter"D"of the antenna wire 1302.

It should be understood that, in this and other embodiments of antennas having wires embedded in rubber strips, that the wire may be other than an elongate helix such as the wire 1220. For example, the embedded wire may be a single elongate strand of wire, multiple strands of wire, a braided wire, or the like. It is also within the scope of the invention that the wire is not a metallic wire at all, but rather conductive pathways, such as of a carbon containing material, and more particularly a carbon fiber, embedded in the rubber strip (s). Other electrically conducting materialsuseful for such conductive pathways include carbon black or particulate graphite.

Conductive rubber compositions are well known, as evidenced, for example, by the disclosures of conductive rubber compositions in commonly-owned U. S. Patent No.

5, 143. 967 (Krishnan, et al.; 1992) and U. S. Patent No.4, 823, 942 (Martin, et al.; 1989), both of which are incorporated in their entirety by reference herein. One having ordinary skill in the art to which the present invention most nearly pertains will appreciate that the choice of one conductive rubber composition over another does not form a critical element of the present invention, per se, but rather will depend upon application-specific parameters, including the composition of the tire surface to which the antenna is mounted, the material of the antenna, and the like.

Figure 13B illustrates an embodiment of an antenna 1320 having two segments made of individual lengths of wire 1322 and 1324 (compare 1302), with each length of wire embedded in a strip of rubber material 1326 and 1328, respectively (compare 1304). The lengths of wire 1322 and 1324 may be straight wires or elongate helixes of wire as described hereinabove.

The strip 1326 of rubber material is elongate, and has two ends, a first end 1326a and a second end 1326b.A first portion 1326c of the strip 1326, extending from the first end 1326a partially toward the second end 1326b, is of a conductive rubber composition, as described hereinabove. A remaining second portion 1326d of the strip 1326, extending from the second end 1326b partially toward the first end 1326a, is optionally (as shown) of a non-conductive rubber composition, as described hereinabove.

The length of wire 1322 is elongate, and has two ends, a first end 1322a and a second end 1322b. A first end portion 1322c of the elongate length of wire 1322, extending from the first end 1322a partially toward the second end 1322b, is embedded in the first portion 1326c of the strip 1326. A second portion 1322d of the wire 1322, is embedded in the second portion 1326d of the strip 1326. A third portion 1322e of the wire 1322 extends out of the second end 1326b of the strip 1326.

The strip 1328 of rubber material is elongate, and has two ends, a first end 1328a and a second end 1328b. A first portion 1328c of the strip 1328, extending from the first end 1328a partially toward the second end 1328b, is of a conductive rubber composition, as described hereinabove. A remaining second portion 1328d of the strip 1328, extending from the second end 1328b partially toward the first end 1328a, is optionally (as shown) of a non-conductive rubber composition, as described hereinabove.

The length of wire 1324 is elongate, and has two ends, a first end 1324a and a second end 1324b. A first end portion 1324c of the elongate length of wire 1324, extending from the first end 1324a partially toward the second end 1324b, is embedded in the first portion 1328c of the strip 1328. A second portion 1324d of the wire 1324, is embedded in the second portion 1328d of the strip 1328. A third portion 1324e of the wire 1324 extends out of the second end 1328b of the strip 1328.

The end portion 1322e of the wire 1322 suitably extends from a patch, for example, as the end portion 864 of the wire 862 in the patch 850, as described hereinabove. Likewise, the end portion 1324e of the wire 1324 suitably extends from a patch, for example, as the end portion 868 of the wire 862 in the patch 850, as described hereinabove.

When installed on an inner surface of a tire, the first end portions 1326c and 1328c of the strips 1326 and 1328, respectively, can be overlapped (as indicated by the dashed lines) and joined with one another so that the two wires 1322 and 1324 form a loop antenna extending completely about the circumference of the inner surface of the tire, as shown for the antenna 1200 in Figure 12A.

As mentioned hereinabove, the end portions 1326c and 1328c of the strips 1326 and 1328, respectively, are preferably formed of a conductive rubber material (composition). In this manner, the two end portions 1322c and 1324c of the wires 1322 and 1324, respectively, can be electrically-connected with one another via the conductive nature of the rubber material within which they are embedded. The conductive rubber

material preferably exhibits as great a conductivity as possible, for example, approximately 10 ohmcentimeters. As is known, this will result in an effective conductive path between the two end portions 1322ca and 1324ca of the wires 1322 and 1324, wherein the conductivity increases in proportion to the overlapping area of the two end portions 1326c and 1328c, and decreases as the distance between the two wire portions 1322c and 1324c.

Figure 13C shows a side cross-sectional view of a tire 1350 (compare 1204), having an inner surface 1352 (compare 1202) and an outer surface 1354, a patch 1356 (compare 1210) having a transponder module (not shown) disposed therein, and a loop (360 degree) antenna 1360 (compare 1200) emanating from two opposite edges of the patch 1356 and spanning the entire circumference of the inner surface 1352 of the tire 1350.

The antenna 1360 has a first elongate section 1362 (compare 1326) extending from the patch at least approximately halfway (180 degrees) around the circumference of the tire, and a second elongate section 1364 (compare 1328) extending from the patch (in the manner described hereinabove) at least approximately halfway (180 degrees) around the circumference of the tire. Distal from the patch, the end portions 1366 and 1368 (compare 1326c and 1328c, respectively) of the antenna sections 1362 and 1364, respectively, are overlapped at a position on the inner surface 1352 of the tire 1350 which is preferably diametrically opposed to the position of the patch 1356. In this manner, the mass of the patch (with transponder disposed therein) can be at least partially counterbalanced by the double thickness of antenna sections in their overlapping end portions 1366 and 1368.

Figure 13D shows a side cross-sectional view of a tire 1350' (compare 1350), having an inner surface 1352' (compare 1352) and an outer surface 1354' (compare 1354), a patch 1356' (compare 1356) having a transponder module (not shown) disposed therein, and a dipole antenna 1360' (compare 1360) emanating from two edges of the patch 1356'and proceeding around the circumference of the inner surface 1352'of the tire 1350'.

The antenna 1360'has a first elongate section 1362' (compare 1362) extending from the patch approximately halfway(180) around the circumference of the tire, and a second elongate section 1364' (compare 1364) extending from the patch (in the manner described hereinabove) approximately halfway(180) around the circumference of the tire. Distal from the patch, the end portions 1366'and 1368' (compare 1366 and 1368, respectively) of the antenna sections 1362'and 1364', respectively, are shown to end before they overlap each other at a position slightly less than 180 around the circumference of the inner surface 1352'of the tire 1350'. Since the ends 1366'and 1368'of the antenna 1360'are electrically isolated from each other, the antenna 1360'becomes a dipole antenna instead of a loop antenna. An alternate embodiment (not shown) for this type of dipole antenna comprises extending the two elongate sections 1362'and 1364'around the circumference more than 180 while still preventing electrical contact between the elongate sections as they pass alongside each other.

Figure 14A illustrates another embodiment of a combination of a transponder module mounted within a patch and an antenna emanating from the patch. Each of these components is similar in some respects to their counterparts in previously-described embodiments, for example: the transponder module 1102, the patch 1100, and the antenna 1320.

A patch 1400 (compare 1100) has an upper surface 1412 (compare 1112) and a lower surface 1414 (compare 1114), and an opening 1420 (compare 1120) extending past a lip 1424 (compare 1124) to a cavity 1422 (compare 1122) within the body of the patch.

A transponder module 1402 (compare 1102) has a housing 1404 (compare 1104) and contact pads 1432 and 1434 (compare 1132 and 1134) disposed on a bottom surface 1406 (compare 1106) of the housing.

The patch 1400 is provided with electrically-conductive contact plugs (slugs) 1452 and 1454 (compare the contact pads 1152 and 1154) extending from within the cavity 1422 to the bottom surface 1414 of the patch 1400. These plugs could be slugs of metal, conductive rubber, or other electrically conductive material. The contact plugs 1452 and 1454 are exposed within the cavity 1422, such as by extending slightly beyond the inner surface 1426 (compare 1126) of the cavity, and are aligned (as indicated by the dashed lines) to make electrical contact with the contact pads 1432 and 1434, respectively, of the transponder module 1402 when the transponder module 1402 is disposed within the cavity 1422 of the patch 1400.

As described hereinabove, in order to ensure proper electrical connection between the transponder contacts and the patch contacts, the pads 1432/1434 and/or plugs 1452/1454 can be extended around the transponder or cavity; or matching irregularities in the transponder and cavity surfaces can be used to register the position of the transponder in the cavity. Alternatively, the transponder and patch contacts can be formed as mating plug/receptacle pairs as described hereinabove with respect to Figure 11A (e. g., 1152'/1132').

An antenna 1440 (compare 1140,1320) comprises two individual lengths of wire 1442 and1444 (compare 1322 and 1324), each length of wire embedded in a strip of rubber material 1446 and 1448 (compare 1326 and 1328), respectively. The lengths of wire 1442 and 1444 may each be elongate helixes of wire as described hereinabove with respect to
Figure 12C. Each strip 1446 and 1448 of rubber material is elongate and, in a manner similar to that previously described with respect to the strips 1326 and 1328, may have two end sections 1446a/1446b and 1448a/1448b, respectively, which are of a conductive material, and a central section 1446c and 1448c, respectively, between the two end sections which is of a non-conductive material.

The conductive end section 1446a of the strip 1446 is aligned (as indicated by the dashed line) with the conductive plug 1452. The conductive end section 1448a of the strip 1448 is aligned (as indicated by the dashed line) with the conductive plug 1454. In the manner described hereinabove with respect to Figure 13C, the strips 1446 and 1448 (compare 1362 and 1364) extend about the circumference of the inner surface (compare 1352) of the tire (compare 1350), where their opposite end sections 1446b and 1448b (compare 1366 and 1368) may be overlapped to electrically connect the wires 1442 and 1444, respectively, embedded therein so as to form a loop antenna within the tire.

Alternatively, a dipole antenna could be formed in the manner described hereinabove with respect to Figure 13D, wherein the end sections 1446b and 1448b (compare 1366'and 1368') would not electrically connect the wire 1442 to the wire 1444. For this dipole antenna embodiment, the end sections 1446b and 1448b would advantageously be made of the same non-conductive rubber as the middle sections 1446c and 1448c.

The patch 1400 and the antenna 1440 (comprising sections 1446 and 1448) may be assembled simply by positioning the patch 1400 on the build drum 610 (preferably in a recess), then laying out the strips 1446 and 1448 with their conductive end sections 1446a and 1448a positioned over the contact slugs 1452 and 1454, respectively; overlapping the end sections 1446b and 1448b of the strips 1446 and 1448, respectively for a loop antenna, or not overlapping for a dipole antenna; and continuing with the lay-up of the tire being fabricated.

Alternatively, the strips 1446 and 1448 can first be mounted or secured to the bottom surface 1414 of the patch 1400. Alternatively, the strips 1446 and 1448 can be integrally formed with the patch 1400, during molding of the patch 1400. One having ordinary skill in the art to which the present invention most nearly pertains will understand these variations, based on the disclosure of various embodiments and techniques set forth herein.

Figure 14B illustrates another embodiment of an antenna 1460. In this embodiment, a full loop antenna can be formed from two lengths of wire 1462 and 1464 (compare 1442 and1444) which are embedded in a single long strip of rubber material 1466 (compare 1446 and 1448). In this embodiment, the strip 1466 is shown as having two end sections 1466a and 1466b (compare 1446a, 1446b, 1448a, 1448b) which are formed of a conductive rubber composition, and a central section 1466c (compare 1446c, 1448c), between the two end sections 1466a and 1466b which is formed of a non-conductive material. This antenna 1460 may be readily substituted for the antenna 1440 of the previously-described embodiment.

As mentioned hereinabove, the antenna strip or strips can first be integrated with the patch itself. For example, as illustrated in Figure 14C, an antenna strip 1460 (of the type shown and described with respect to Figure 14B) can be placed in a mold 800 (of the type shown and described with respect to Figure 8) so as to be molded integrally with a patch.

Furthermore, conductive plugs 1452 and 1454 (of the type shown and described with respect to Figure 14A) may be disposed in the mold, so as to be molded into the resulting patch.

Regarding the various antennas (e. g., 740) for transponder modules described hereinabove, one having ordinary skill in the art to which the invention most nearly pertains will understand that various aspects of

antenna design, such as the overall length of a loop antenna, the lengths of the legs of a dipole antenna, impedance, and the like, depend largely on the frequency (or frequencies) at which the antenna is intended to operate, as well as the desired propagation and reception characteristics of the antenna in a given environment. It should be understood that the present invention is not limited to any particular operating frequency for the antenna, however, specific mention is made of the antennas disclosed herein being suitable to operate at 124 kHz or 13.56 MHz.

ALTERNATE COUPLING AND MOUNTING ARRANGEMENTS
As described hereinabove, a single patch may hold a coupling coil of an-antenna in close proximity to a coupling coil in a transponder module disposed in the patch, so that transformer-type coupling can be effected between the two coupling coils. Attention is now directed to alternate embodiments of the invention which employ other (than a single patch) techniques for holding a transponder in close proximity to an antenna's coupling coil so that comparable transformer-type coupling may occur.

MOUNTING THE ANTENNA AND ITS COUPLING COIL
Figures 15A and 15B illustrate, in top plan and cross-sectional views, respectively, a patch 1500 with an integral coupling coil 1538 (compare 968) on a bobbin 1530 (compare 961), and two segments of an antenna 1520 (compare 970) having end portions 1522 (compare 972) and 1524 (compare 974) in the patch body 1501, and extending out of opposite sides 1513 of the patch body 1501 in the form of antenna strips 1523 (compare 1300). As best viewed in Figure 15B, the antenna coupling coil patch (coupling coil patch or simply"patch") 1500 and antenna strips 1523 are suitably mounted to a pneumatic tire 1550 by being attached on the tire's inner surface 1504 (compare 604). The inner surface 1504 is shown as an inner liner over a carcass layer such as ply 1506 (compare 606) with cords 1508 (compare 608) disposed therein. The inner surface 1504 is representative of the inside layer or wall of the overall tire 1550, and the coupling coil patch of the present invention, in its various embodiments disclosed herein, is not limited or restricted to any particular tire construction.

The patch body 1501 has a substantially flat bottom surface 1514, a substantially flat top surface 1512, and a side portion 1513 which tapers from a periphery of the flat top surface 1512 down to the periphery 1516 of the bottom surface 1514.

In the manner described hereinabove (e. g., with respect to Figure 13A), the antenna 1520 (compare 1220,1302) suitably comprises a helical wire embedded in a strip 1523 (compare 1304) of rubber material 1521 which is suitable for bonding to an inside surface of a pneumatic tire. As mentioned hereinabove, the strip 1523 preferably has a flat side suitable for bonding to a substantially flat inside surface of a pneumatic tire, and may have a tapered profile. As described hereinabove, the antenna 1520 may be of one piece (loop) or two pieces (dipole), and can be formed from a variety of conductive materials, elongate or coiled in a helix. The rubber material 1521 used in the patch body 1501 and antenna strip 1523 are suitably the materials described hereinabove with respect to previously-described embodiments of the invention, and could be different from each other.

Figure 15C illustrates an alternate embodiment wherein a coupling coil patch 1500' (compare 1500) has an integral coupling coil 1538' (compare 1538) on a bobbin 1530' (compare 1530), and an antenna 1520' (compare 1520) having two end portions 1522' (compare 1522) and 1524' (compare 1524) in the patch body 1501' (compare 1501) and extending out of opposite sides 1513' (compare 1513) of the patch body 1501'in the form of antenna strips 1523' (compare 1523). In this example, rather than the patch 1500'being attached on an inner surface 1504' (compare 1504) of the pneumatic tire 1550', the patch 1500'comprising body 1501'and antenna strip (s) 1523'are mounted to the tire 1550'by being embedded under the inner surface 1504', preferably during the tire manufacturing process. The material 1521' (compare 1521) in the patch body 1501'and antenna strip 1523'is a suitable elastomeric material such as uncured rubber of the same formulation as the inner liner 1504' (compare 1504).

Figure 15D illustrates an alternate embodiment of a technique for mounting an antenna and a coupling coil to an inside surface of a pneumatic tire, without using a patch.

In this embodiment, a coupling coil1538" (compare 1538') on a bobbin1530" (compare 1530'), with an antenna1520" (compare 1520') having two end portions1522"/1524" (compare1522'/1524') extend from opposite sides of the coupling coil1538" (compare 1538'). Instead of first being formed into a patch with body and antenna strips (e. g., 1500' with 1501'and 1523'), the coupling coil1538"on bobbin 1530", and antenna1520"are all directly embedded under the surface of the inner liner1504" (compare 1504') of tire1550" (compare 1550'), preferably during the tire manufacturing process.

Figures 15A, 15B, 15C and 15D illustrate the example of using a helical coiled wire for the antenna 1520,1520', 1520" (compare 1220). As illustrated in Figures 15A and 15B, theheights"HI"and"H2"of the patch body 1501 and the antenna strip 1523, respectively, may be suitably similar (approximately1-3 mm, such as approximately 1.25mm) ; although the antenna strip 1523 may be lower ("H2"lessthan"HI"), in which case the tapered surface 1513 will slope down from the top patch surface 1512 to merge in a gradual curve with the top and side surfaces of the antenna strip 1523. The coupling coil 1538 (and/or bobbin 1530, if present) may have an outerdiameter"DI"of approximately 25-60 mm, such as32 mm ; the patch body's substantially flat top surface 1512 may have a diameter"D2", concentricto"DI"and 0-10 mm greater in diameterthan"DI". The height "H3"of the coupling coil (and/or bobbin, if present) may be the sameas"HI", less than"HI" (as shown), or morethan"HI", depending on design variations detailed hereinbelow.

The center of the patch and coil/bobbin may have an alignment depression or hole 1535 fashioned in the patch's rubber or in the bobbin's central portion or potting compound disposed therein. The hole 1535 is one of many possible"mating features"which can be used to position and possibly hold a transponder being attached to the antenna coupling coil 1538. A bobbin 1530,1530',1530"is illustrated in the figures, but it is within the scope of this invention that a coupling coil 1538,1538',1538"can be employed in various embodiments without the use of a bobbin.

As with previous embodiments of patches described hereinabove (see Figure 6B for example), the patch/coupling coil/antenna 1500,1500', 1500"of the present invention is suitably incorporated into (mounted to) a pneumatic tire in the course of the various tire plies being"laid up"on the outer surface (e. g., 611) of a tire build drum (e. g.,610).

However, it should be understood that the patch 1500and many of its various embodiments described herein, can also be attached on an inner surface of a tire which has already been fabricated. In whatever way the present invention is mounted to the inside surface of a tire, whether attached on, or embedded under the inner surface, it should be understood that antenna wires which emerge from opposite sides of the invention (e. g., antenna wires 1520 emerging from coupling coil 1538 and patch body 1501) are designed to be disposed about the circumference of the tire similar to the manner illustrated in Figures 12A, 12B, 13C, or 13D, and the antenna wire may also be either attached on or embedded under the inner surface about the circumference of the tire.

The coupling coil 1538,1538', 1538"is suitably made in the manner of the coils 938,968 or 1004 with bobbins 930,961 or 1002 (as described in Figures 9A, 9B, 9C, and10A). Alternate forms of coupling coil/bobbin constructions are illustrated in Figures 16A and16B.

ALTERNATE ANTENNA COUPLING COIL CONSTRUCTIONS

Figure 16A illustrates a coupling coil wire 1638 (compare 1538,938,1004) wound by known coil-winding methods into an annular coil with outsidedimensions"DI"and "H3", matching those dimensions of Figures 15A and 15B. Inside diameter"D3"is greater than the diameter of the desired mating feature hole 1635' (compare 1535), and is determined by the wire diameter and number of coil turns most suitable to the coil's intended function as a coupling coil for a matching transponder. The two ends of the wire 1638 emerge from the coil at approximately opposite sides and connect to the ends 1622/1624 (compare 1522/1524) of the antenna wire 1620 (compare 1520). So that it will maintain its shape, the coil is optionally impregnated with non-conductive potting compound or elastomeric material, and optionally bound with a wrapping 1639 of paper, plastic, string or other suitable non-conductive materials.

Figure 16B illustrates a similar coupling coil 1638'disposed within a chamber (bobbin) 1630 made of a non-conductive material, such as plastic, which can maintain its shape and integrity through the tire's manufacturing (especially the curing step) and the life of the tire's use. The coil of wire 1638'may be separately formed (as 1638 in Figure 16A) and then inserted into the bobbin 1630, or it may be formed within the bobbin by methods which are not the subject of this patent. In order to do the latter, there may be added features to the shape and design of the bobbin 1630, but only the features important to this application are illustrated. The bobbin 1630 is a round chamber shaped like a cylindrical dish, open at the top, with vertical side wall 1637a, and substantially flat bottom surface 1637b. The cylindrical center hole 1635 (compare 1535) shown here is optionally provided as a mating feature, and is formed out of an optional interior wall 1637c of the bobbin. The empty space 1631 within the bobbin 1630 and around the coil 1638'is optionally filled with potting compound or other suitable non-conductive filler including rubber. The antenna wires 1620 (compare 1520) may be threaded through holes, or preferably as shown, laid into

vertical slots 1623 in the outside wall 1637a of the bobbin 1630, wherein the slots 1623 are open at the top of the bobbin wall 1637a.

ALTERNATE TRANSPONDER MOUNTING TECHNIQUES

There are now described various techniques for attaching transponder modules to the coupling coil/antenna assemblies described hereinabove in reference to Figures 15A, 15B, 15C, 15D, 16A and 16B. For optimum electrical coupling between the transponder's coupling coil and the antenna's coupling coil which is attached on or embedded under the surface of the inside tire wall (e. g., inner liner), it is preferable that the transponder's coupling coil be placed in close proximity and concentric to the antenna's coupling coil.

Other aspects of the invention, as mentioned above, include making the transponder removable, replaceable and/or repairable, allowing it exposure to ambient conditions within the tire, and making it possible for heat-sensitive components (such as can be in the transponder) to be added to a tire after it has been cured. Figures 17A and 17B illustrate two embodiments of this invention which accomplish these objectives.

Figures 17A and 17B illustrate transponder-holding patches 1700 and 1700'which attach to tire inner surface 1704 which contains an embedded coupling coil 1738,1738' (compare 1538,1638) which is continuous with its associated antenna wires 1720 (compare 1520,1620) also embedded under the inner surface 1704 and extending around the circumference of the tire as described hereinabove. It is within the scope of this invention that the surface of inner liner 1704 could alternatively represent the surface 1512 of patch 1500 as described hereinabove, which could be attached on the tire's inner surface (e. g., 1504), or embedded under it (e. g., 1504'). It is also within the scope of this invention that the coupling coil 1738,1738'could be any coupling coil similar to those described hereinabove (e. g., 938,968,1004,1538,1638), and could be employed as-is, or including a bobbin such as 930,961,1002,1530, or 1630.

The embodiments of Figures 17A and 17B can be seen as a two-part version of the patch 980 of Figure 9C. The transponder module 1751,1752 (compare 951) with its own coupling coil (not shown, compare 953) is removably held in the cavity 1790,1790' (compare 990) by a flexible annular lip 1788,1788' (compare 988) which extends somewhat into the circular opening 1786,1786' (compare 986).

Mating features for enabling desired positioning of the transponder 1751,1752 relative to the coupling coil 1738,1738'are now described. The patches 1700,1700'are circular with outside diameter"D2"which is concentric with the circular transponder module ofdiameter"Dl"which, in turn, is approximately equal to the outside diameter of the coupling coil 1738,1738' (compare 1538,1638) or the bobbin 1730 (compare 1530, 1630) if present (shown in Figure 17B, but not in Figure 17A). In instances where the transponder patch 1700,1700'will be attached to a surface-mounted coupling coil patch such as 1500, then the patch 1700,1700'diameter"D2"is approximately equal to or less than the corresponding"D2"outside diameter of the flat top surface 1512 of patch 1500. In other instances, the diameter"D2"can be any suitable dimension which will enable secure and durable attachment of the transponder patch 1700,1700'to the surface of inner liner 1704.

The patch 1700 has top surface 1782, first bottom surface 1784, and parallel second bottom surface 1785. The surface 1785 is flat and circular, concentric with the cavity 1790, and having the same outsidediameter"Dl"as the coupling coil 1738. The surface 1785 is stepped down from the surrounding surface 1784 by a small stepheight"Xl" (e. g., approximately 0.4 mm), creating a circular protrusion 1787. To receive this patch, the coupling coil 1738 has been recessed below the top surface of inner liner 1704 to a depth "X2"which is at least as much asdimension"Xl". This recess 1737 should have the same (or slightly larger)diameter"Dl"as the protrusion 1787 on the patch so that the protrusion 1787 can mate with the recess 1737 when the patch 1700 is affixed to the surface of inner liner 1704. The recess 1737 could be formed by a mandrel in the mold used to form patch 1500, or by a removable disc placed atop the coupling coil 1738 (compare 1638) when it is embedded in the tire inner wall, or by other known means. Alternatively, if a bobbin such as 1630 is employed to contain the coupling coil, then the recess 1737 could be created by extending the bobbin's outer wall 1637a above the top of the coupling coil 1638' (and also above any potting or filler which may be disposed within the bobbin) by the distance"X2".

In this case, the inside diameter of the bobbin wall 1637a would have to be designed to match or slightly exceed thediameter"Dl"of the protrusion 1787 on the patch 1700.

Another mating feature (positioning means) is illustrated by Figure 17B. The patch 1700'has top surface 1782', and substantially flat bottom surface 1784'. In the center of the bottom surface 1784'is an approximately round protrusion 1755 with diameter"D4"and height"H4"designed to enable the protrusion 1755 to mate with the hole 1735 in the coupling coil/bobbin1738'/1730 embedded under the tire inner surface (or coupling coil patch) 1704. The protrusion 1755 is preferably a rounded peg-like bump, but may be of any shape suitable for mating with the hole 1735, and could be formed as part of the bottom surface 1784'of the molded elastomeric patch 1700'. Alternatively, the protrusion 1755 could be a feature of the transponder module 1752, extending through a matching hole (not shown) in the center of the bottom surface 1784'of the patch 1700'. To receive this patch 1700', the coupling coil/bobbin1738'/1730 (compare 1538/1530,1638'/1630) would be embedded under the surface 1704 of the liner/patch (compare 1504 or 1512) with the top of 1738'flush with the surface 1704, as shown. Hole 1735 could be a depression formed by a mandrel or removable insert when the coupling coil 1738' (compare 1638) is embedded in a patch such as 1500 or under the tire inner surface such as 1504. Alternatively, the hole 1735 could be formed as part of a bobbin (e. g., 1530 or 1630) containing the coupling coil (e. g., 1538 or 1638'). Dimension"D4"indicates the protrusion's outer diameter and the hole's inner diameter, which are approximately equal with allowance made for easy mating of the two (for example, a difference of approximately 0.25mm between the two diameters). Diameter"D4"can be any suitable value up to"D3"of Figures 16A and 16B which is the inside diameter of the coupling coil 1738' (compare 1638,1638'). The protrusion height"H4"can be any suitable value (such as 1mm) providing it is less than the height"H3"of the hole 1735 (compare 1535,1635) as shown in Figure 15B.

It is within the scope of the invention that the protrusions and mating recesses could include, for example, that the protruding surface 1785 could instead be recessed in the patch 1700 (not shown, but similar to transponder 1852'in Figure 18B), and then the coil/bobbin1738'/1730 could be fashioned so that it protruded in a corresponding way above the surface 1704 of the liner/patch, as seen for coil/bobbin1838'/1830'in Figure 18B. Other variants of the above described protrusions and mating recesses may be evident to one skilled in the art which most nearly pertains to this invention, and should be considered to be within the scope of this invention.

If the objectives of transponder removability and accessibility are not important, then several other transponder attachment methods are suggested by the above discussion. These also should be considered within the scope of this invention as long as they utilize the concepts described hereinabove, wherein a separate transponder module is aligned with and held against a coupling coil/antenna assembly which is attached on or embedded under the surface of the inner liner of a pneumatic tire (e. g., Figures 15A, 15B 15C and 15D). For example, the patch 1700 could be closed on the top, having no opening 1786. Access to the cavity 1790 allowing insertion of transponder 1751 would be through a new opening on the bottom of the patch (eliminating protrusion 1787 and bottom surface 1785). The cavity height could be sized either more or less than the transponder height, so that the transponder would either protrude into the recess 1737, or would be recessed to mate with a coupling coil 1838'made to protrude above the surface 1804 of the inner liner/patch. A similar treatment of patch 1700'could be used to attach a transponder 1752 above coil/bobbin1738'/1730 if the transponder 1752 had a protrusion 1755 to mate with hole 1735.

In all of the examples described hereinabove, mating surfaces of the elastomeric transponder-holding patches are attached to a pneumatic tire's inner surface (e. g., 1704) or to the top surface of a coupling coil patch (e. g., 1512,1512') and/or to the coupling coil 1738,1738'and/or to a bobbin (if present, e. g., 1730) by known means such as suitable adhesives, curing together, and other means of bonding rubber and other elastomeric parts.

This attachment can be made during or after the tire manufacturing process, and the adhesive can be of a"permanent"type without affecting the removability of the transponder held within the patches 1700/1700'.

If the objective of transponder removability can be sacrificed, then some other means of transponder attachment to the above described coupling coil/antenna assemblies are made possible without the use of patches. For example, the transponder module 1751 itself could be affixed to 1738 in the recess 1737 using a suitable adhesive. In like fashion, the transponder 1752 could be affixed to a coupling coil/bobbin1738'/1730 providing the transponder had a protrusion 1755 which mated with hole 1735 as shown in Figure 17B.

Figure 18A illustrates an alternate"removable"embodiment. Here the mating feature, protrusion 1855 (compare 1755) on the bottom of transponder 1852 (compare 1752) is fashioned as a screw, eitherself-

tapping or with cylindrical machine screw threads. The mating hole 1835 (compare 1635) would be formed in the center portion of the bobbin 1830 (compare 1630) which would be containing the coupling coil 1838 (compare 1638,1738, 1738'), both of which would be embedded under the tire or patch surface 1804 (compare 1704). The hole 1835 would be of a diameter sufficient to receive the screw-shaped protrusion 1855, and suitably thread-tapped, or not, as appropriate to mate with 1855. To prevent this version of transponder 1852 from unscrewing itself during tire use, the threads of 1855 could be staked, or coated with thread-locking compound, or use other known means to make them"locking". Alternatively, a lock-washer could be disposed between the bobbin and transponder, or the bottom surface 1854 of transponder 1852 could be fashioned with radial saw-tooth ridges (not shown) which would be angled to make unscrewing difficult. Other options which may or may not be removable include the use of adhesive between or around the mating elements.

Figure 18B illustrates an alternate technique for attaching a transponder directly above a coupling coil/bobbin. Here it can be seen that the coupling coil/bobbin1838'/1830' (compare1638'/1630) extends above the surface of the rubber 1804 (either a tire inner liner, or a patch such as 1500) which surrounds it. Although the embodiment illustrated in Figure 18B shows a bobbin 1830'with the coupling coil 1838', it is within the scope of this invention that the coupling coil 1838'could be similar to coupling coil 1638, without a bobbin. The cylindrical outside housing wall 1883 (compare 258) of the transponder 1852' (compare 1852) has been extended downward below the bottom surface 1885 (compare 256,1854) to create a recess 1887. The surface 1885 is flat and circular, contained within the protruding wall 1883. The protruding wall 1883 has an inside diameter "Dlb"which is the same as, or slightly more than, thediameter"Dl"of the coupling coil/bobbin 1838'/1830'with which it is intended to mate. The wall 1883 protrudes below the contained surface 1885 to create a small recessdepth"Xl" (e. g., approximately0. 4 mm). To receive this transponder, the coupling coil/bobbin 1838'/1830'would protrude above the surface 1804 of the liner/patch to a height"X2"which is approximately equal todimension"Xl". The transponder 1852'can be affixed around the protrusion 1837 and thus be positioned directly above the coupling coil/bobbin 1838'/1830'using any suitable adhesive. Although this embodiment sacrifices removability, it has the advantage of allowing for a minimum separation between the transponder's coupling coil and the antenna's coupling coil, because the bottom wall 1885 of the transponder module 1852'can have a minimum thickness (such as approximately 0.3 mm) and not have a negative impact on the overall strength or performance of the transponder housing. It can be seen that the protrusions and recesses described hereinabove are mating features which will provide for suitable positioning and holding when the transponder is to be attached to the antenna coupling coil.

Figures 19A through 19F illustrate additional alternate techniques for attaching a transponder in close proximity to a coupling coil/antenna such as 1500. These techniques utilize"housings"rather than"patches"as transponder holders, but similarly provide for transponder removability, replaceability, maintainability, and access to tire atmosphere; provide freedom to insert the transponder at any point in the tire manufacturing process; and have minimal impact on tire performance. It will be seen that various features of the housing, the antenna coupling coil, and even the transponder module are mating features which will accomplish these objectives.

Figures 19A and 19B illustrate, in top and cross-sectional side views, respectively, an embodiment of a transponder holder in the form of a housing 1900 with resilient"clipfingers"1902a.. 1902f (fingers 1902) for holding a transponder module (transponder) 1951 (compare1751).

The housing 1900 is preferably shaped like a circular, straight-sided dish, with a substantially flat bottom wall 1982, substantially flat outside bottom surface 1984, and annular side wall 1983 surrounding the cavity 1990 which is open at the top. Surrounding the top opening 1986, the wall 1983 has a rounded retaining lip 1988 which protrudes radially inward by an amount"t3" (approximately 0.25-2.0 mm, such as approximately1. 0 mm) sufficient to serve as a detent to hold the transponder inside the cavity. The bottom edge of the lip 1988 defines the top of the transponder holding area within the cavity 1990, and is a distance"H5"above the inside surface of bottom wall 1982."H5"is designed to be equal to, or slightly (e. g., approximately 0.25 mm) larger than the height"Q"of the transponder 1951. Likewise, the holding area's inside diameter"Dla"is designed to be slightly (e. g., approximately 0.25 mm) larger than the outsidediameter"Dl"of the transponder1951.

The transponder 1951 is illustrated with a preferred straight-sided, cylindrical disk shape, but it is within the scope of this invention that the transponder 1951 could be any shape having a"retaining edge"1953 at the periphery of its top surface. This retaining edge 1953 would conform to the shape and inside dimensions of the cavity 1990,1990', 1990", 1990"', in a way which causes the transponder 1951 to be

retained below the lip 1988 of the fingers 1902.

To allow the lip 1988 to expand enough to ease insertion of the transponder 1951 into the cavity 1990 a plurality of vertical cutouts 1904 are notched into the side wall 1983.

Although six cutouts 1904a to 1904f are shown, creating the six fingers 1902a to 1902f, the quantity could be any number (e. g., 2 to 30) deemed suitable to allow insertion, removal, and holding of the transponder module1951. The housing wall thickness"tl"is another factor in the design of the fingers 1902a..1902f (fingers 1902), and is designed accordingly (suitably 0.3-3.0 mm, such as approximately1. 0 mm).

The housing 1900 is suitably made from a resilient material such as a plastic selected to withstand the operating environment inside a pneumatic tire, with a combination of rigidity, flexibility, and strength necessary to allow the transponder 1951 to be pushed past the fingers 1902a..1902f into place in the cavity 1990 of the housing 1900, and to removably retain the transponder 1951 in the cavity 1990 during the lifetime operations of the pneumatic tire in which it is placed.

The clip finger style of transponder holder 1900 can be positioned above, and attached to, a coupling coil/antenna (e. g., 1500) inside a tire in a variety of ways similar to those described for Figures 17A, 17B, 18A and 18B.

The housing 1900 is designed to be positioned via a mating feature comprising a protrusion1955 (compare 1755) of the bottom surface 1984 (compare 1784'). The protrusion 1955 has dimensions"H4"and"D4"which match those dimensions for 1755 as deemed suitable for mating with the coupling coil and/or bobbin mating features as described hereinabove. The wall of the bottom surface 1984 has a thickness"t2"of approximately 0.3-3.0 mm such as approximately 1.0 mm, and is designed as thin as possible consistent with good design for suitable strength. Once positioned by the protrusion 1955, the housing 1900 can be held in place by any suitable adhesive applied to surfaces 1984 and/or 1955, and/or around the bottom edge of 1983.

Alternatively, the protrusion 1955 could be fashioned as a screw (not illustrated) in the same ways described for protrusion 1855 in Figure 18A, and then the housing 1900 could be attached by screwing it into a correspondingly fashioned hole in the coupling coil/bobbin (not shown, compare hole 1835 incoil/bobbin 1838/1830) as described hereinabove. An advantage of the transponder holder (housing) 1900 versus transponder 1852 is that housing 1900 can be affixed with a permanent adhesive and still allow a transponder such as 1951 to be removed.

In a general sense, the transponder holder 1900 of Figures 19A and 19B performs the same function as the patch 1700'of Figure 17B, and is similarly provided with mating features such as a protrusion 1955 (compare 1755) for mating with a hole (e. g., 1735) in a coupling coil/bobbin (e. g., 1738'/1730) embedded under a tire inner surface (e. g., 1704), or with a hole (e. g., 1535,1535') in a coupling coil patch (e. g., 1500,1500').

Figures19C, 19D and 19E illustrate alternate embodiments of transponder holders (housings) 1900', 1900"and1900"' (compare 1900), and are substantially identical in their construction to the aforementioned housing 1900 (of Figures19A, 19B) with regard to their top portions including cavities 1990', 1990",1990"'for retaining transponder modules (e. g.,1951), and differ mainly in the construction of their bottom portions with the mating features designed to mate with an underlying antenna coupling coil arrangement. For example, the bottom surface of the housing 1900'of Figure19C is stepped in a manner similar to that of the bottom surface of the patch 1700 illustrated in Figure 17A. For example, the bottom surface of the housing1900"of Figure 19D is recessed in a manner similar to that of the bottom surface of the transponder module 1852'illustrated in Figure 18B.

Figure19C illustrates an embodiment of a transponder holder (housing) 1900'which is designed to be positioned via a mating feature comprising a stepped bottom surface1984'/1985', in the same manner as the patch 1700 in Figure 17A. The housing 1900'has first bottom surface 1984' (compare 1784), and parallel second bottom surface 1985' (compare 1785). The surface 1985'is flat and circular, concentric with the cavity 1990 (compare 1790), and having an outside diameter"Dla"which is the same as, or slightly less than, thediameter"Dl"of the coupling coil/bobbin (not shown, compare 1738) and the recess it sits in (not shown, compare 1737). The surface 1985'is stepped down from the surrounding surface 1984'by a small stepheight"Xl" (e. g., approximately 0.4mm), creating a circular protrusion 1987' (compare 1787). To receive this housing, the coupling coil (not shown, compare 1738) would be recessed below the liner/patch

surface (not shown, compare 1704) to a depth"X2"which is at least as much asdimension"XI". The housing 1900'can be affixed in the recess above the coupling coil using any suitable adhesive.

Figure 19D illustrates an embodiment of a transponder holder (housing)1900" wherein the shape of the bottom portion of the housing1900"is the"inverse"of housing 1900', and is designed to mate the housing1900"with a coupling coil/bobbin (e. g.,1838'/1830') which protrudes (e. g., 1837) above the surface of the liner/patch surrounding it (e. g., 1804). Housing 1900"has first bottom surface1984", and parallel second bottom surface1985". The surface1985"is flat and circular, concentric with the cavity 1990, and having an inside diameter"Dlb"which is the same as, or slightly more than, the diameter"Dl"of the coupling coil/bobbin (e. g. 1838'/1830') with which it is intended to mate. An annular protrusion1987"is a downward extension of the outer wall1983", and projects surface1984"below the contained surface 1985"by a small stepheight"XI" (e. g., approximately 0.4 mm). To receive this housing, the coupling coil/bobbin (e. g., 1838'/1830') would protrude above the surface of the inner liner/patch (e. g., 1804) to a height"X2"which is approximately equal todimension"XI". The housing 1900"can be affixed above the coupling coil/bobbin using any suitable adhesive. An advantage of the design of housing1900"is that the bottom wall of surface 1985"can have a minimum thickness"t2", such as approximately 0.3 mm, and not have a negative impact on the overall strength or performance of the transponder housing. This allows closer proximity between an antenna coupling coil and a transponder such as 1951 in the housing1900" affixed above the coupling coil (e. g., 1838').

Figure 19E illustrates an embodiment of a transponder holder (housing)1900'" wherein the bottom portion is similar to that of the housing1900", except that it has been formed as an integral bobbin to contain a coupling coil such as is described with respect to
Figures 16A and 16B. The housing1900'"has a top cavity1990'" (compare 1990", 1990', 1990) designed to removably hold a transponder module such as 1951 described hereinabove. Below the wall1982'" (compare 1637b) is a bottom chamber 1933 designed like a bobbin (compare 1630) to permanently hold a coupling coil 1938 (compare 1638').

The cylindrical side wall1987'" (compare 1637a) of bottom chamber 1933 is formed by extending wall1983'"downward a distance"H3"sufficient to contain the coupling coil 1938 (e. g., distance"H3"of Figure 16B, approximately1-3 mm, such as approximately 1.25 mm). As in Figure 16B, the coupling coil 1938 (compare 1638') which may have been formed separately or in the chamber, has two wire ends 1922/1924 (compare 1622/1624) which are connected to antenna wires 1920 (compare 1620) which extend through holes (or preferably slots) 1923 (compare 1623). The empty space 1931 (compare 1631) surrounding the coil 1938 in the chamber 1933 can be filled with potting compound or other suitable non-conductive filling material. Thus, the housing1900'"serves as a combined transponder holder and bobbin with contained coupling coil, with an antenna extending therefrom. Therefore, the housing1900'"performs a function similar to that of patch 980 of Figure 9C. Since the antenna coupling coil is already part of the transponder holder 1900'", the transponder-to-coil mating feature would become the retaining edge (e. g., 1953) of the transponder (e. g., 1951) to the housing clip fingers (e. g., 1902) with their retaining lip (e. g., 1988).

After assembling the housing1900'", as described hereinabove, it can be employed in a tire by embedding at least a portion of the coupling coil-containing bottom chamber 1933 (along with its integral antenna 1920) in a patch such as 1500 or 1500', or similarly embedding chamber/antenna 1933/1920 directly in the tire wall under the inner surface such as1504".

It is within the scope of the invention to accommodate the housing1900'"in the following way during tire construction: If a patch containing the housing/antenna1900'"/1920, or the housing/antenna1900'"/1920 by itself, is to be embedded under a tire's inner surface (e. g., 1504 or 604), then provision for the top portion of housing1900'" could be made in the form of a corresponding cavity in the tire build drum (e. g., 610) sized to retain housing1900'"in position during tire building, with the desired amount of wall1983'"protruding above the tire's inner surface (e. g., 1504).

Finally, at any time after the heat of tire curing and the like, the transponder (e. g.,1951) can be inserted into the open top cavity1990'" (compare 622) of the bobbin/housing 1900'"which is embedded under, or attached to the surface of the inner liner (e. g., 1504, 1202) of a tire (e. g., 1204). It should be apparent that this same technique using a cavity in the tire building drum could be employed to fashion a bobbin/coil such as1838'/1830'of
Figure 18B which can be embedded under the inner surface but protrudes out of it.

Although the descriptions of Figures 19A through 19E illustrate transponder holders with cylindrical side walls, it is within the scope of this invention to utilize the described clip finger transponder-holding technique in a housing with non-cylindrical side walls (e. g., square in the top view), as long as the shape of the cavity 1990,1990',1990", 1990"'conforms to the shape of the retaining edge 1953 of the transponder 1951 which is to be retained by the lip 1988 of the clip fingers 1902.

Figures 19A through 19E illustrate housings with an exemplary apparatus/technique, using resilient clip fingers 1902 (e. g., 1902a..1902f), for removably holding a transponder, and several techniques for positioning and attaching (mating) the transponder to an antenna coupling coil in a tire. Figure 19F illustrates an alternate technique for removably holding a transponder1951a (compare 1951), generally comprising a housing with two main components: a holder 1900a, and a cap 1901.

The holder 1900a has a circular chamber 1990a, surrounded by a cylindrical side wall 1983a, a substantially flat bottom wall 1982a, and has an opening 1986a at the top.

The chamber 1990a is sized as above to hold a transponder1951a withdiameter"Dl"and height"Q". The side wall 1983a has a screw thread fashioned in its outer surface with a thread diameterof"D5". The side wall inside diameter is slightly (e. g., approximately 0.25mm) larger than the outsidediameter"Dl"of the transponder1951a, and has a thickness"t5" (e.g.. 0.3-3.0 mm, such as approximately 1.0 mm) suitable to perform as needed with a thread applied on one side. Thus, for a transponder1951a which may havediameter"Dl" of 25-60 mm (e. g.,32 mm),"D5"may be 25.6-66.5 mm (e. g., 34.25 mm).

The cap 1901 is designed to screw down onto the holder 1900a to removably hold an inserted transponder1951a in the chamber 1990a while still allowing the transponder access to the internal atmosphere of the pneumatic tire in which it is mounted. Cap 1901 is circular, with sidewall 1957 and top wall 1959 surrounding a hollow cavity as shown. The top wall 1959 has a concentric, circular opening 1956 with lip 1958 and diameter"D6" designed to be at least 1 mm smallerthan"Dl", the diameter of the transponder 1951a being held in place by the lip 1958. Diameter"D6"can be as small as desired as long as it allows suitable exposure of the transducer's sensor (s) to the tire's inner atmosphere as needed. The opening 1956 may even be absent (i. e., a solid top wall 1959) if the transducer 1951 does not need continuous access to the tire's inner atmosphere, or if a sensing hole is otherwise provided through another wall of holder 1900a and/or cap 1901. The inside surface of sidewall 1957 is threaded to mate with the thread on the outside surface of sidewall 1983a, and has a suitable effective thread diameter of approximately"D5". The thickness of the walls 1957 and 1959 are similar to of the walls of holder 1900a, and are chosen to be suitable for their intended function.

The height of sidewalls 1957 and 1983a must be sufficient to allow overlapping of a suitable number of threads when the two parts 1900a and 1901 are screwed together around a contained transponder1951a. The top 1989 of sidewall 1983a is shown as ending below the top of transducer1951a so that cap 1901 can be screwed down tightly over transducer1951a, holding it in place. The resulting space between the sidewall top 1989 and the cap's top wall 1959 could be filled with an appropriately sized o-ring or a locking washer. In an alternate embodiment, the wall 1983 could extend higher so that the top 1989 is above the top surface of transducer 1951a and will therefore provide a stop for the cap 1901 when wall 1959 touches sidewall top 1989 as cap 1901 is screwed onto holder 1900a.

The transponder 1951a is illustrated with a preferred straight-sided, cylindrical disk shape, but it is within the scope of this invention that the transponder1951a could be any shape (such as a rectangular block) providing it is sized to fit within the cavity 1990a but outside the diameter of the opening 1956 in the cap 1901. Therefor, such a cavity-sized transponder1951a would encompass a cylindrical space with a diameterbetween"D1"and "D6", and with a heightof"Q".

> The bottom surface 1984 of holder 1900a is shown with protrusion 1955 for positioning and attachment the same as housing 1900 of Figure 19B. It should be evident that any of the mating features described hereinabove and built onto the bottom portion of housings 1900,1900', and1900"could be applied in like fashion to a housing with the top portion fashioned as the holder/cap 1900a/1901 just described; therefore all of these variations are intended to be within the scope of the described invention. In like manner, it is also within the scope of this invention to fashion the top portion of housing1900"'as a holder/cap 1900a/1901 with the bottom portion containing the antenna coupling coil 1938. Since the antenna coupling coil is already part of the such a transponder holder, the transponder-to-coil mating feature would become the cavity-fitting dimensions of the transponder 1951a to the screw-threaded holder/cap walls 1983a/1957.

Although the invention has been illustrated and described in detail in the drawings and foregoing description, the samé is to be'considered as illustrative and not restrictive in character, it being understood that only preferred embodiments have been shown and described, and that all changes and modifications that come within the spirit of the invention are desired to be protected. Undoubtedly, many other"variations"on the"themes"set forth hereinabove will occur to one having ordinary skill in the art to which the present invention most nearly pertains, and such variations are intended to be within the scope of the invention, as disclosed herein.

MOUNTING TRANSPONDERS AND ANTENNAS IN PNEUMATIC TIRES

Claims of **WO0136221**

What is claimed is:
1. Apparatus for mounting a transponder module (400,702,951,1000,1020, 1751,1752,1852,1852', 1951,1951a) having a transponder coupling coil (450,760,953, 1004,1024), an antenna (740,740', 862,940,970,1200,1300,1302,1320,1360,1360', 1520,1520',1520", 1620,1720,1820,1920) and an antenna coupling coil (750,750', 866,938,968,1538,1538',1538", 1638,1638', 1738,1738', 1838,1838', 1938) to an inner surface (1504,1504', 1504", 1704,1804) of a pneumatic tire (312,650,1204,1350, 1350', 1550,1550', 1550"), characterized in that: the transponder module is attached to the antenna coupling coil, in a way which positions the transponder coupling coil in close proximity and concentric to the antenna coupling coil, thereby providing effective transformer-type coupling between the transponder and the antenna.

2. Apparatus, according to claim 1, characterized in that: the antenna (1302,1520,1620,1720,1820,1920) is disposed within elongate strips of elastomeric material (1304,1521) to form antenna strips (1300,1523); the antenna coupling coil (1538,1638,1638', 1738,1738', 1838,1838', 1938) is disposed within a body (1501) of an antenna coupling coil patch (1500); and the antenna and the antenna coupling coil are mounted to the inner surface (1504) of the tire (1550) by attaching the antenna strips and the antenna coupling coil patch on the inner surface of the tire.

3. Apparatus, according to claim 1, characterized in that: the antenna (1302,1520', 1620,1720,1820,1920) is disposed within elongate strips of elastomeric material (1304,1521') to form antenna strips (1300,1523'); the antenna coupling coil (1538', 1638,1638', 1738,1738', 1838,1838', 1938) is disposed within a body (1501') of an antenna coupling coil patch (1500'); and the antenna and the antenna coupling coil are mounted to the inner surface (1504', 1704,1804) of the tire (1550') by embedding the antenna strips and the antenna coupling coil patch under the inner surface of the tire.

4. Apparatus, according to claim 1, characterized in that: the antenna(1520", 1620,1720,1820,1920) and the antenna coupling coil(1538", 1638,1638', 1738,1738', 1838,1838', 1938) are mounted to the inner surface(1504", 1704,1804) of the tire(1550") by embedding the antenna and the antenna coupling coil under the inner surface of the tire.

5. Apparatus, according to claim 1, characterized in that: the antenna coupling coil is provided with a first mating feature and the transponder module is provided with a corresponding second mating feature for attaching the transponder module to the antenna coupling coil; the first mating feature is selected from the group consisting of a recess (1535,1535',1535", 1635,1635', 1737,1735), a protrusion (1837), a mating hole (1535, 1535',1535", 1635,1635', 1835), clip fingers (1902) with retaining lip (1988), and screwthreaded holder/cap walls (1983a/1957); and the corresponding second mating feature is selected from the group consisting of a protrusion (1787,1755,1955,1987'), a recess (1887,1987"), a screw-shaped protrusion (1855), a retaining edge (1953) of the transponder module (1951), and a dimension of the transponder module (1951a).

6. Apparatus, according to claim5, characterized in that: the first mating feature is provided on the antenna coupling coil (1638, 1738).

7. Apparatus, according to claim 5, characterized in that: the first mating feature is provided on a bobbin (1530,1530',1530", 1630, 1730,1830,1830',1982'"/1987'") which contains the antenna coupling coil (1538,1538', 1538", 1638', 1738', 1838,1838', 1938).

8. Apparatus, according to claim 7, characterized in that: the bobbin is a resilient housing (1630,1900'"), with a chamber (1630, 1933), a bottom wall (1637b,1982'"), and a surrounding side wall (1637a,1987'") ; the antenna coupling coil (1638', 1938) is contained in the chamber, and has two wire ends (1622/1624,1922/1924) extending through slots (1623,1923) in the side wall; and the antenna (1620,1920) is electrically connected to the two antenna coupling coil wire ends.

9. Apparatus, according to claim 5, characterized in that: the second mating feature is provided on a transponder holder (1700,1700', 1900,1900',1900", 1900a/1901) having a cavity (1790,1790',

1990,1990',1990", 1990a) for removably holding the transponder module (1751,1752,1951,1951a).

10. Apparatus, according to claim 9, characterized in that: the transponder holder is an elastomeric patch (1700,1700') having a first external surface (1782,1782'), at least a one second external surface (1784,1784', 1785) opposite the first external surface, an opening (1786,1786') extending through the first external surface to the cavity (1790,1790') in the body of the patch, the cavity being sized and shaped to be approximately the same size and shape as the transponder module (1751, 1752); and the opening has a smaller dimension than the cavity, thereby forming a resilient lip (1788,1788') about the opening, the lip being sized to be somewhat smaller in a corresponding dimension than the transponder module so that the transponder module may be inserted through the opening into the cavity by deflecting the lip and thereafter retained within the cavity by the annular lip.

11. Apparatus, according to claim 9, characterized in that: the transponder holder is a resilient housing (1900,1900',1900"), removably holding the transponder module (1951) in the cavity (1990,1990', 1990"); the cavity has a surrounding side wall (1983,1983',1983"), a bottom wall (1982), and a top opening (1986); the opening has an annular retaining lip (1988) which protrudes inward, and a plurality of vertical cutouts (1904) are notched into the side wall, creating a plurality of resilient clip fingers (1902); and the transponder module has a retaining edge (1953) at the periphery of its top surface which conforms to the shape and inside dimensions of the cavity so that the transponder module may be inserted through the opening past the lip into the cavity by deflecting the clip fingers, and thereafter be retained within the cavity by the transponder module retaining edge held below the annular retaining lip.

12. Apparatus, according to claim 9, characterized in that: the transponder holder(1900a/1901) is a resilient housing having a first part(1900a) and a second part (1901), which together removably hold the transponder module(1951a) in the cavity(1990a) ; the first part(1900a) of the resilient housing is a holder with the cavity, and has a cylindrical surrounding side wall (1983a) with screw threads on the outside surface, a bottom wall (1982a), and a top opening (1986a); the second part (1901) of the resilient housing is a removable screw cap, and has an annular side wall (1957) with screw threads on the inside surface, and a top wall (1959) with an opening (1956) of a dimension smaller than the size of the cavity, thereby forming a lip (1958) around the opening; and the second part of the housing is designed to be screwed onto the first part of the housing to cap the transponder holding cavity, and the diameter of the opening of the lip is sized to be smaller than a corresponding dimension of the transponder module, so that the transponder module may be inserted through the opening in the first part and thereafter be retained within the cavity by the lip of the second part which is screwed onto the first part.

13. Apparatus, according to claim 5, characterized in that: the second mating feature is provided on a surface (1854,1885) of the transponder module (1852,1852').

14. Method of mounting a transponder module (400,702,951,1000,1020, 1751,1752,1852,1852', 1951,1951a) having a transponder coupling coil (450,760,953, 1004,1024), an antenna (740,740', 862,940,970,1200,1300,1302,1320,1360,1360', 1520,1520', 1520", 1620,1720,1820,1920) and an antenna coupling coil (750,750', 866,938,968,1538,1538',1538", 1638,1638', 1738,1738', 1838,1838', 1938) to an inner surface (1504,1504',1504", 1704,1804) of a pneumatic tire (312,650,1204,1350, 1350', 1550,1550',1550"), characterized by: attaching the transponder module to the antenna coupling coil, in a way which positions the transponder coupling coil in close proximity and concentric to the antenna coupling coil, thereby providing effective transformer-type coupling between the transponder and the antenna.

15. Method, according to claim 14, characterized by: mounting the antenna and the antenna coupling coil to the inner surface of the tire by attaching the antenna and the antenna coupling coil on the inner surface of the tire.

16. Method, according to claim 14, characterized by: mounting the antenna and the antenna coupling coil to the inner surface of the tire by embedding the antenna and the antenna coupling coil under the inner surface of the tire.

17. Method, according to claim 14, characterized by: disposing the antenna (1302,1520,1620,1720,1820,1920) within elongate strips of elastomeric material (1304,1521) to form antenna strips (1300,1523); disposing the antenna coupling coil (1538,1638,1638', 1738,1738', 1838, 1838', 1938) within a body (1501) of an antenna coupling coil patch (1500); and mounting the antenna and the antenna coupling coil to the inner surface (1504) of the tire (1550) by attaching the antenna strips and

the antenna coupling coil patch on the inner surface of the tire.

18. Method, according to claim 17, characterized by: attaching the antenna strips and the antenna coupling coil patch on the inner surface of the tire during the fabrication of the tire.

19. Method, according to claim 17, characterized by: attaching the antenna strips and the antenna coupling coil patch on the inner surface of the tire after the fabrication of the tire.

20. Method, according to claim 14, characterized by: disposing the antenna (1302,1520', 1620,1720,1820,1920) within elongate strips of elastomeric material (1304,1521') to form antenna strips (1300,1523'); disposing the antenna coupling coil (1538', 1638,1638', 1738,1738', 1838, 1838', 1938) within a body (1501') of an antenna coupling coil patch (1500'); and mounting the antenna and the antenna coupling coil to the inner surface (1504', 1704,1804) of the tire (1550') by embedding the antenna strips and the antenna coupling coil patch under the inner surface of the tire.

21. Method, according to claim 14, characterized by: mounting the antenna(1520", 1620,1720,1820,1920) and the antenna coupling coil(1538", 1638,1638', 1738,1738', 1838,1838', 1938) to the inner surface (1504", 1704,1804) of the tire(1550") by embedding the antenna and the antenna coupling coil under the inner surface of the tire.

20. Method, according to claim 14, characterized by: providing the antenna coupling coil with a first mating feature and providing the transponder module with a corresponding second mating feature for attaching the transponder module to the antenna coupling coil; selecting the first mating feature from the group consisting of a recess (1535, 1535',1535", 1635,1635', 1737,1735), a protrusion (1837), a mating hole (1535,1535',1535", 1635,1635', 1835), clip fingers (1902) with retaining lip (1988), and screwthreaded holder/cap walls (1983a/1957); and selecting the corresponding second mating feature from the group consisting of a protrusion (1787,1755,1955,1987'), a recess (1887,1987"), a screw-shaped protrusion (1855), a retaining edge (1953) of the transponder module (1951), and a dimension of the transponder module(1951a).

21. Method, according to claim 20, characterized by: providing the first mating feature on the antenna coupling coil (1638,1738).

22. Method, according to claim 20, characterized by: providing the first mating feature on a bobbin (1530,1530', 1530", 1630, 1730,1830,1830',1982'"/1987'") which contains the antenna coupling coil (1538,1538',1538", 1638', 1738', 1838,1838', 1938).

23. Method, according to claim 20, characterized by: providing the second mating feature on a transponder holder (1700,1700', 1900,1900', 1900",1900a/1901) having a cavity (1790,1790', 1990,1990', 1990", 1990a) for removably holding the transponder module (1751,1752,1951,1951a).

24. Method, according to claim 20, characterized by: providing the second mating feature on a surface (1854,1885) of the transponder module (1852,1852').

25. Method, according to claim 14, characterized by: attaching the transponder module to the antenna coupling coil during the fabrication of the tire.

26. Method, according to claim 14, characterized by: attaching the transponder module to the antenna coupling coil after the fabrication of the tire.

27. A transponder module (200) having a transponder coupling coil (450), characterized by: a coupling coil (1004,1024) on the external surface (258,1002,1022,1883) of the transponder module (200,400,500,1000,1020,1751,1752,1852,1852',1951, 1951a).

28. A transponder module, according to claim 27, characterized by: a recess (1006) in the external surface of the transponder module for receiving the transponder coupling coil.

29. A transponder module, according to claim 27, characterized in that: the transponder coupling coil has ends (552/554) which extend through corresponding openings (556/558) in the external wall of the transponder module to within the transponder module.

30. A transponder module, according to claim 27, characterized by: an other coupling coil (1026) disposed on an inside surface of the transponder module.

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